NISTIR 4504

# A Field Study of the Performance of EPDM Roofing at Air Force Facilities



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National Institute of Standards and Technology
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*Prepared for:*
**U.S. Air Force**
Air Force Engineering and Services Center
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Tyndall, FL 32403

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# A Field Study of the Performance of EPDM Roofing at Air Force Facilities

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January 1991

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ABSTRACT

A study was conducted at the request of the Air Force Engineering and Services Center to obtain and analyze information on the in-service performance of low-sloped EPDM roofing systems at Air Force installations. Because of the benefits to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems, the Air Force has proposed developing a guide specification for EPDM roofing. Technical data are needed to support the development of the guide specification. The information obtained in the study contributes to the data base.

Fifteen USAF installations in 11 states were visited, and 61 EPDM roofs were inspected. This represented about 50 percent of the number of Air Force installations and buildings with EPDM roofing. The age of the roof systems ranged from 3 to 156 months, although 40 percent were only 30 months old or less. The inspections were performed by walking over the roofs during which notes were recorded and photos were taken. During the field visits, discussions were held with base engineering personnel to determine their views of the performance of EPDM roofing under their responsibility. Considering the relatively young age of the roofs inspected, their overall performance was found to be satisfactory. About half were visually seen to be in fine condition, while another third displayed only minor defects which were limited in scope and were considered to be readily reparable with routine maintenance. On a less positive note, in the latter case, the observed defects had gone without repair. This illustrated a key concern expressed by field personnel that they lacked ability to perform routine maintenance.

Key words: EPDM; field survey; inspection; low-sloped roofing; membrane; performance; roofs; seams

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## EXECUTIVE SUMMARY

Since the mid-1970s, low-sloped roofing practices in the United States have undergone significant changes regarding both the types of membrane and insulation materials and also the application methods employed in the installation of the systems. The most notable change has been the "single-ply" revolution, whereby membranes consisting of elastomeric, thermoplastic, or polymer-modified bituminous materials have replaced bituminous built-up membranes as the waterproofing component of low-sloped roofs.

Roofing practices of the construction branches of the U.S. Department of Defense (DOD) agencies, in general, mirror those of the U.S. roofing industry. However, drastic changes in practice, such as those experienced by the roofing industry in the single-ply revolution, may not be quickly followed by DOD. The DOD construction branches generally take a conservative approach to the use of new materials, and gain experience showing that new products can provide satisfactory performance before widespread substitution for the traditional materials is made.

As a consequence of the conservative approach to materials substitution, the use of the single-ply membrane materials by the DOD agencies has not increased to the extent that has occurred in the private sector. For example, the use of the relatively new membrane systems has been considered by the U.S. Air Force (USAF) as experimental and has been limited. As a result, the Air Force has not developed guide specifications for single-ply roofing systems and, to date, reports on the use of the newer systems at USAF facilities have not been published.

In cases where the newer membrane systems have been installed, architect-engineering personnel at USAF field installations have generally been required to report annually to the Air Force Engineering and Services Center (AFESC) at Tyndall Air Force Base on their performance, and note any maintenance (other than inspection) undertaken. This program is providing the Air Force with a performance database on the use of newer systems at USAF facilities. However, until the present study, a formal analysis of the database had not been undertaken.

The Air Force has considered that benefits are to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems. The annual reports submitted by USAF field personnel have indicated that, although not problem-free, the newer systems have generally performed well. Thus, as a first step in providing a mechanism for the field installations to have latitude in selecting membrane roofing systems, the Air Force has proposed developing a guide specification for ethylene propylene diene terpolymer (EPDM) roofing at USAF facilities. Technical data are needed to support the development of the guide specification. To assist in developing the needed data, the AFESC requested that the National Institute of Standards and Technology (NIST) conduct a study of the use and performance of EPDM roofing at USAF facilities.

The objective was to obtain and analyze information on the in-service performance of low-sloped EPDM roofing systems at Air Force installations. The files on EPDM roofing at the AFESC were reviewed for information on performance factors such as roof age, location, method of membrane attachment, overall condition, problems reported, and maintenance performed. Visits were made to selected air bases to observe firsthand the performance of these systems. A limited number of seam samples were taken to conduct laboratory tests for their characterization.

The review of the AFESC data file on new roofing systems was the first step of the study. It provided information on the extent of EPDM roofing at USAF installations as well as comments on performance made by field personnel, and allowed planning of the field inspections of the roofs. Data from 31 installations were in the file, and represented 123 USAF buildings of undetermined size with EPDM roofing systems. This was quite limited, in view of the amount of EPDM roofing used in recent years in the United States. The EPDM systems represented membrane products (brand names) from 11 manufacturers, although three of the 11 accounted for about 70 percent of the recorded installations. The roofs were constructed between 1976 and 1988, although the majority were installed in 1982 or later.

Comments on the performance of the EPDM roofs were provided in the AFESC data file for 22 of the 31 installations. These comments were brief, and where problems were noted, lacked detail that enabled full understanding of the nature and extent of the problem. This reflected the summary nature of the data file and the brevity of the descriptions. The majority of the comments were positive and implied satisfactory performance, using expressions such as "excellent condition," "no problems to date," "performing well," and "no maintenance." In contrast, six installations reported some problem which involved a total of 16 roofs. Many of these problems such as leaks at flashings, penetrations, and gravel stops, as well as wind damage to the membrane, were typical for roofing in general, and not specific to EPDM.

Fifteen USAF installations in 11 states were visited, and 61 EPDM roofs were inspected. This represented about 50 percent of the number of installations and buildings with EPDM roofing in the AFESC data file. The inspections encompassed a variety of building types including hangars, hangar lean-tos, commissaries, dormitories, gyms, offices, shops, clubs, and mess halls. None of the buildings were considered to have extraordinary interior temperature and humidity conditions.

EPDM systems from eight manufacturers were represented in the roof sampling. However, consistent with the AFESC database of USAF EPDM roofs, two manufacturers accounted for about 50 percent of the roofs inspected. The age of the roof systems ranged from 3 to 156 months. For the vast majority of the roof systems, the membrane was either adhered (about 50 %) or ballasted (about 40 %), with only three roofs having the membranes mechanically fastened. Half of the ballasted

membranes were incorporated in protected membrane roof (PMR) systems with the insulation above the membrane and under the ballast.

The field inspections showed that the comments in the AFESC data file indicating generally satisfactory performance of the roofing adequately reflected performance at a majority of the installations visited. In contrast, in a few cases, the file comments indicated good performance, but the field inspections found problems and, in some cases, no comments were given in the file, but problems were observed with the roofs.

During the visits to the installations, discussions were held with field personnel to learn their experiences with EPDM roofing. The major concern voiced by field personnel was the maintenance and repair of EPDM roofs. Many stated that they are not adequately knowledgeable about inspection procedures, and suggested that training methods for proper inspection of EPDM roofing by USAF personnel be developed. In a related matter, many field personnel raised concerns that they could not perform satisfactory routine maintenance or even emergency repairs to the EPDM roofs, because they had neither the training nor the materials. Consequently, they urged that such methods be developed for the field installations, particularly if the use of EPDM increases with the development of a guide specification.

During the field visits, 13 seam samples with ages ranging from 11 to 60 months were obtained from six installations. The majority were taken from roofs whose seams were performing satisfactorily although, in two cases, performance was unsatisfactory. Using Fourier Transform Infrared (FTIR) spectroscopy, the types of adhesive in the seam samples were identified. The majority had butyl-based adhesive, while two had neoprene-based adhesive.

Average values for peel strength and adhesive thickness of the seam specimens were determined. No relation between these two parameters was found. The peel strengths ranged from 0.21 to 1.0 kN/m (1.2 to 5.9 lbf/in.), which was comparable to those measured for other field-fabricated seams. Generally, butyl-based seams have strengths greater than neoprene-based seams. In the present study, the strengths of two of the butyl-based samples were similar to those of the two neoprene-based seams.

With the exception of specimens from one installation, the thicknesses of the adhesive layers were 0.20 mm (0.008 in.) or less. These values were comparable to adhesive thicknesses found for other field-prepared seams, and have been considered to be relatively thin. Seams having relatively thin adhesive layers may not be as resistant to peel failure under creep conditions, as they could be if they had thicker adhesive layers.

At one installation, the seam specimens had extremely thick adhesive layers, ranging from 1.3 to 1.5 mm (0.052 to 0.060 in.). The seams of two of these roofs had not performed satisfactorily, which was attributed to the excessive fishmouths and wrinkling of the membrane at the laps. The relatively thick adhesive layers may have

contributed to the formation of the fishmouths and wrinkles, because of the retention of solvent during seam fabrication.

Scanning electron microscopy (SEM) was conducted on one seam sample from each of the six installations. It was found that:

- o Adhesive and rubber surfaces exposed due to interfacial failure during peel testing showed the presence of platelet particles indicative of release agent.

- o Some specimens showed the presence of micro-cavities within the adhesive layers. These micro-cavities may be considered as defects in the adhesive layer which would contribute to lower-than-expected peel strength of the bond when failure is cohesive (and the micro-cavities were not present).

To provide a general assessment of the overall performance of EPDM roofing at the USAF installations, a numerical, though subjective, ranking system was devised for assigning a rating to the roofs inspected. The rating system devised was based on two factors: (1) the field observations made by NIST research staff, and (2) the discussions held with field personnel during the inspections. The ratings assigned to each roof ranged from 1 to 5 as follows:

| Rating | Basis |
|---|---|
| 5 | No defects were observed; discussions with field personnel raised no major concerns with performance. |
| 4 | Defects, very limited in scope, were found on the roof; in these cases, it was considered that routine maintenance could readily repair the defects; or a condition was seen that had apparently not affected the functioning of the roof, but was considered to require close attention during future inspections; discussions with field personnel raised no major concerns with performance. |
| 3 | A number of defects were found on the roof; although numerous, it was considered that routine maintenance techniques could readily repair the defects; discussions with field personnel raised no major concerns with performance. |
| 2 | Significant defects were observed and were considered to require more than routine maintenance to repair them; discussions with field personnel raised major concerns with an aspect of the roof's performance. |
| 1 | Significant defects were found to the extent that replacement of the roof would be considered as a repair option; during discussions, field personnel raised major concerns with some aspect of the performance of the roof. |

The ratings assigned to each of the roofs were based on their condition as seen and discussed at the time of the inspection. If a past repair (e.g., patch) had been made to a roof that was found to be performing satisfactorily, then the assigned rating reflected the current performance and did not consider that a repair had been necessary. A limitation of the rating system was that it considered only the observations made of the visible portions of the roof system. Extensive sampling of the roofing components to measure properties or evaluations to determine the presence and extent of moisture within the roofs was beyond the scope of the study. A summary of the ratings assigned to the roofs is:

| Rating | Number of Roofs | Percent of Total Roofs Rated |
|---|---|---|
| 5 | 28 | 47 |
| 4 | 22 | 37 |
| 3 | 2 | 3 |
| 2 | 7 | 12 |
| 1 | 0 | 0 |

It should be remembered that the majority of the roofs were less than 5 years old. With consideration of this relatively young age, as is evident from the summary above, the overall performance of the EPDM roofs inspected at the USAF installations was considered to be satisfactory. That is, about half of the roofs were visually found to be in fine condition, while another third displayed only minor defects which were very limited in scope and were considered to be readily reparable with routine maintenance. For both categories, field personnel expressed no concerns about performance.

On a less positive note, most of the roofs with a 4 rating contained minor defects, which were in need of repair. As previously indicated, a key concern expressed by field personnel is their lack of ability to perform routine maintenance.

Seven roofs (12 percent) were considered to have defects beyond the type easily reparable by routine maintenance, and would require more extensive attention. These included:

- 3 roofs with seam problems
- 1 roof with deteriorated neoprene-based base flashing
- 1 roof with significant fastener backout
- 1 roof with small membrane splits around the edges of stress plates used with mechanical fasteners. This roof had also experienced wind damage to an adhered membrane and field personnel were uncertain whether the problem would recur.
- 1 roof with extensive ponding

None of the above problems are unique to the USAF. The four problems with seams and deteriorated neoprene-based base flashing are typical of EPDM roofing. Wind and fastener problems are more associated with mechanically fastened single-ply systems, and not specifically EPDM. And, finally, the one problem of extensive ponding of water has no association with any specific type of membrane, but is a function of slope and drainage of the low-sloped roof system.

Based on the results of the inspections and discussions held with field personnel, a number of lessons were learned for the USAF to bear in mind in developing its guide specification for EPDM roofing.

Three key conclusions from the study are as follows:

- o Considering the relatively young age of the roofs inspected, their overall performance was found to be satisfactory. About half were visually seen to be in fine condition, while another third displayed only minor defects which were very limited in scope and were considered to be readily reparable with routine maintenance.

- o Where reparable minor defects were observed, they had gone without repair. This illustrated a key concern expressed by field personnel that they are limited in making routine or emergency repairs to EPDM roofing.

- o NDE methods are needed to assess the condition of seams; for this critical performance parameter, a walk-over roof inspection does not allow an assessment of the interior portions of seams.

# 1. INTRODUCTION

## 1.1 Background

Since the mid-1970s, low-sloped roofing practices in the United States have undergone significant changes regarding both the types of membrane and insulation materials and also the application methods employed in the installation of the systems [1]. The most notable change has been the "single-ply" revolution, whereby membranes consisting of elastomeric, thermoplastic, or polymer-modified bituminous[1] materials have replaced bituminous built-up membranes as the waterproofing component of low-sloped roof systems. From little use in 1975, the annual installation of single-ply systems reached, by 1988, about 60 percent of all membrane roofing installed, with about three quarters of this percentage being ethylene propylene diene terpolymer (EPDM) rubber membranes [2,3].

Roofing practices of the construction branches of the U.S. Department of Defense (DOD) agencies, in general, mirror those of the U.S. roofing industry. However, drastic changes in practice, such as those experienced by the roofing industry in the single-ply revolution, may not be quickly followed by DOD. The DOD construction branches generally take a conservative approach to the use of new materials, and gain experience showing that new products can provide satisfactory performance before widespread substitution for the traditional materials is made. For example, the Corps of Engineers has been conducting a field program evaluating the performance of experimental single-ply systems to provide data to support the development of guide specifications [4,5].

As a consequence of the conservative approach to materials substitution, the use of the single-ply membrane materials by the DOD agencies has not increased to the extent that has occurred in the private sector. As an example, a 1989 rough estimate of EPDM roofing at 73 major Army bases indicated that a minimum of 800 buildings has these membrane systems [6]. The number of buildings having low-sloped roofs at these installations may be estimated at about 15,000[2], which is quite large relative to the number of EPDM roofs constructed. Based on its experiences, the Corps of Engineers has published a guide specification for EPDM roofing [7].

The amount of single-ply roofing used by the U.S. Air Force (USAF) is less than that used by the Army. The USAF roofing program is under the direction of the Air Force Engineering and Services Center (AFESC) at Tyndall Air Force Base. Over the past decade, the Air Force has focused its roofing practices on built-up roof (BUR) systems, developing [8] and revising [9] a BUR management program.

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[1]Although generally included in the category of "single ply," polymer-modified bituminous membranes often consist of more than one ply.

[2]A. Knehans, U.S. Army Corps of Engineers, Personal Communication.

The use of the relatively new membrane systems has been considered by the Air Force as experimental, and has been limited. As a result, the Air Force has not developed guide specifications for single-ply roofing systems and, to date, reports on the use of the newer systems at USAF facilities have not been published.

To use the newer membrane systems, architect-engineering personnel at USAF field installations have generally needed a waiver on the BUR management program from the AFESC. As part of the waiver process, base facility engineers are required to report annually to the AFESC on the performance of the new system, and note any maintenance (other than inspection) undertaken. This program is providing the Air Force with a performance database on the use of newer systems at USAF facilities. However, until the present study, a formal analysis of the database had not been undertaken.

Although several types of single-ply membranes have been used by the USAF, the majority are EPDM rubber. The Air Force has considered that benefits are to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems. The annual reports submitted by USAF field personnel have indicated that, although not problem-free, the newer systems have generally performed well. Thus, as a first step in providing a mechanism for the field installations to have latitude in selecting membrane roofing systems, the Air Force has proposed developing a guide specification for EPDM roofing at USAF facilities.

Technical data are needed to support the development of the guide specification. To assist in developing the needed data, the AFESC requested that the National Institute of Standards and Technology (NIST) conduct a study of the use and performance of EPDM roofing at USAF facilities. This report presents the results of the study. In addition to the benefits gained by the Air Force in having available firsthand information on its EPDM roofing, the study provided an opportunity for NIST to contribute to the development of data on in-service performance and problems associated with the newer roofing systems. In 1987, participants at the Industry Round Table convened to discuss needs for roofing research indicated that data from the field are needed not only to document in-service performance, but to provide a sound basis for selecting the important problems that require study and solution through research [10].

## 1.2 Objective and Scope of the Study

The objective of the study was to obtain and analyze information on the in-service performance of low-sloped EPDM roofing systems at Air Force installations. The files on EPDM roofing at the AFESC were reviewed for information on performance factors such as roof age, location, method of membrane attachment, overall condition, problems reported, and maintenance performed. Visits were made to selected air bases to observe firsthand the performance of these systems. A limited number of seam samples were taken to conduct laboratory tests for their characterization. Discussions were held with base engineering personnel to determine their views of the performance and maintenance of EPDM roofing under their responsibility.

## 2. THE USE OF EPDM ROOFING AT AIR FORCE FACILITIES

### 2.1 The AFESC Data File on New Roofing Systems

The review of the AFESC data file on new roofing systems was the first step of the study. It provided information on the extent of EPDM roofing at USAF installations as well as comments on performance made by field personnel, and allowed planning of the field inspections of the roofs. Table 1 presents a summary of the data given in the AFESC file for roofs with EPDM membranes. The main features of the data file were the location of the installation (e.g., air base), number of EPDM roofs per installation, membrane material manufacturer, age of the roofs (i.e., year of construction), and comments from field personnel on performance. Data were not always included for all variables for each record of an individual roof. It was realized when the review was undertaken that, for many reasons, the data in the file might not be complete.

At the time of the review (1989), data from 31 installations were in the file, and represented 123 USAF buildings of undetermined size with EPDM roofing systems. This was quite limited, in view of the amount of EPDM roofing used in recent years in the United States [3]. For the buildings in question, the EPDM systems represented membrane products (brand names) from 11 manufacturers, which covered a broad segment of the industry. However, three of the 11 manufacturers accounted for about 70 percent of the recorded installations.

The roofs were constructed between 1976 and 1988, although the majority were installed in 1982 or later. Figure 1 shows the number of installations per year. Note that the year of construction was not always given in the data file as Figure 1 only makes reference to 113 roofs. No roofs were recorded for 1989 because the data file had not been updated at the time of the review.

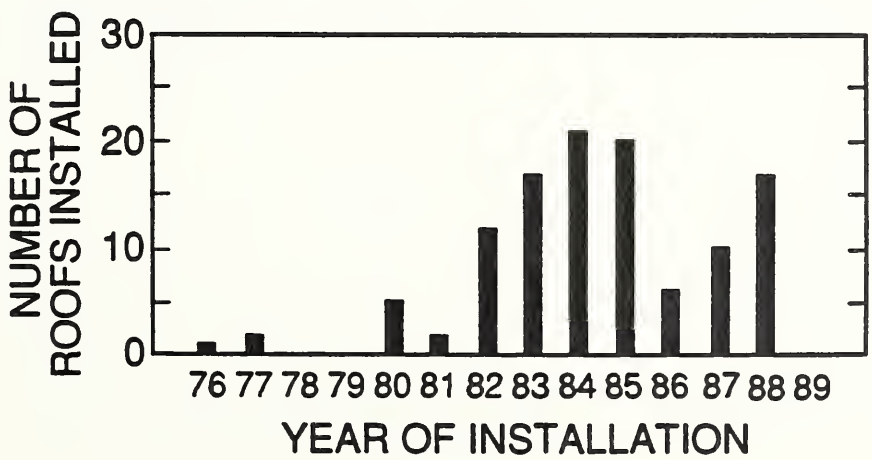


Figure 1. Number of EPDM roofs installed per year, as recorded in the AFESC data file

Table 1. Summary of the AFESC data file on EPDM roofing performance

| Air Force Installation | EPDM Roofs | Manuf Code[a] | Construction Year(s) | Comments on Performance |
|---|---|---|---|---|
| Bolling, DC | 1 | J | 1982 | ---[b] |
| Cannon, NM | 5 | J | 1983 | --- |
| Chanute, IL | 1 | -[c] | 1982 | flashing deteriorated |
| Clear, AK | 1 | E | 1987 | performing well, recommend wider use |
| Eielson, AK | 12 | A,E | 1976 - 1986 | excellent condition, no problems, performing well |
| Ellsworth, SD | 1 | A | 1988 | --- |
| Elmendorf, AK | 8 | A,I, J | 1980 - 1985 | 3 roofs: no leaks reported<br>1 roof: disk cutting rubber<br>4 roofs: penetration leaks |
| F.E. Warren, WY | 1 | E | 1986 | no known problems |
| Grissom, IN | 1 | E | 1984 | high wind damage |
| Kelly, TX | 1 | E | 1988 | --- |
| King Salmon, AK | 3 | A,I | 1984 | no maintenance |
| K.I. Sawyer, MI | 3 | A,B | 1977 - 1986 | no problems to date |
| Lackland, TX | 1 | A | 1984 | no problems |
| Langley, VA | 1 | A | 1982 | no leaks |
| Loring, ME | 4 | B,F | 1987 & 1988 | no maintenance |
| Malmstrom, MT | 3 | C,E | 1988 | --- |
| New Boston, NH | 4 | D | 1984 | good performance |
| Offutt, NE | 13 | A,E | 1981 - 1988 | --- |
| Pease, NH | 2 | A | 1982 & 1988 | no problems |
| Pittsburgh IAP | 2 | E | 1983 | 1 roof: good to date<br>1 roof: seam repairs |
| Plattsburg, NY | 7 | C | 1987 | 6 roofs: repair gravel stops |
| Reese, TX | 1 | G | 1985 | no problems |
| Scott, IL | 5 | A,E | 1981 - 1988 | no maintenance, excellent condition |
| Shemya, AK | 2 | A | 1985 & 1987 | no maintenance |
| Sonderestrom, Greenland | 23 | K | 1982 - 1985 | performing well, no maintenance |
| Thule, Greenland | 6 | A | 1983 - 1987 | 1 roof: flashing leaks<br>1 roof: damaged<br>others: no comments |
| Westover, MA | 1 | A | 1987 | --- |
| Whiteman, MO | 1 | H | 1988 | --- |
| Wright-Patt, OH | 6 | E | 1982 - 1987 | no repairs to date |
| Wurtsmith, MI | 2 | E | 1986 & 1988 | --- |
| Youngstown, OH | 1 | A | 1982 | no maintenance |

[a]This is the code letter for the manufacturer of the membrane system.
[b]The dashed line indicates that no comments were given in the file.
[c]This information was not available in the file.

Comments on the performance of the EPDM roofs were provided for 22 of the 31 installations (Table 1). These comments were brief, and where problems were noted, lacked detail that enabled full understanding of the nature and extent of the problem. This reflected the summary nature of the data file and the brevity of the descriptions on performance submitted by field personnel. The majority of the comments (about 70%) were positive and implied satisfactory performance, using expressions such as "excellent condition," "no problems to date," "performing well," and "no maintenance." Such comments were received from 16 installations and represented 70 buildings. In contrast, six installations reported some problem which involved a total of 16 roofs whose sizes were not given in the file.

These are summarized as follows:

- Chanute AFB: 1 roof with deteriorated flashing.
- Elmendorf AFB: 4 roofs with leaks at penetrations; 1 roof with the fastener disks cutting the rubber membrane.
- Grissom AFB: 1 roof with wind damage to the membrane.
- Pittsburgh AFRES: 1 roof with seam repairs.
- Plattsburg AFB: 6 roofs with leaks at gravel stops.
- Thule AB: 1 roof with flashing leaks; 1 roof which was "damaged," but no explanation was given.

Many of the problems summarized here will be discussed in following sections describing the results of the field survey. The installations at Chanute, Elmendorf, and Pittsburgh were visited during the study. Phone contact was made with facility engineers at Grissom and Plattsburg, who indicated that the problems were repaired and performance had been satisfactory since then. Note that many of the reported problems such as leaks at flashings, penetrations, and gravel stops, as well as wind damage to the membrane, are typical for roofing in general [3]. For example, the facility engineer at Grissom stated that the problems there were due to faulty design of the gravel stops, and not the membrane system. After repair of the gravel stops, the roofs have reportedly been problem free.

## 3. FIELD INSPECTIONS OF USAF EPDM ROOFING

### 3.1 Summary of the Roofs and Installations Visited

The field inspections were planned after the review of the AFESC data file. Table 2 summarizes the field inspections including the bases visited, the number of EPDM roofs inspected at each base, a code for the membrane manufacturer, age of the roof, and the type of membrane securement. The practical aspects of time and travel were considered in setting the itineraries. For example, the roofs in Greenland were not included in the inspections, although they comprised almost 25 percent of the EPDM roofs in the AFESC data file.

Fifteen USAF installations in 11 states were visited, and 61 EPDM roofs were inspected. This represented about 50 percent of the number of installations and buildings with EPDM roofing in the AFESC data file. The inspections were performed by walking over the roofs during which notes were recorded and photos were taken. Not all EPDM systems at each installation visited were inspected, because of practical limitations such as roof access or security. At some installations, one or more of the EPDM roofs, which were not walked over, were indirectly observed from the roof of an adjacent building. In these instances, roof performance was discussed with base personnel. Roofs not directly observed by a walk-over are not included in the summary given in Table 2. No notable problems were indicated for these roofs.

The inspections encompassed a variety of building types including hangars, hangar lean-tos, commissaries, dormitories, gyms, offices, shops, clubs, and mess halls. None of the buildings were considered to have extraordinary interior temperature and humidity conditions, although kitchens or similar facilities were included.

EPDM systems from eight manufacturers were represented in the roof sampling. However, consistent with the AFESC database of USAF EPDM roofs (Table 1), two manufacturers accounted for about 50 percent of the roofs inspected. The age of the roof systems ranged from 3 to 156 months. Figure 2 presents a frequency plot (in 5-month increments) of the ages of the roofs inspected. As evident in Figure 2, the ages of the inspected roofs were well spread over the range up to 110 months, although about 40 percent were 30 months old or less. For the vast majority of the roof systems, the membrane was either adhered (about 50 %) or ballasted (about 40 %), with only three roofs having the membranes mechanically fastened. Half of the ballasted membranes were incorporated in protected membrane roof (PMR) systems with the insulation above the membrane and under the ballast.

Samples of adhesive-bonded field seams were taken at six installations from 12 roofs (Table 2). The decision whether to cut seam samples from the roofing was made by facilities personnel after discussions with NIST and AFESC staff. Practical considerations such as the availability of properly trained mechanics to make patches, ease of access to the roofs for patching, and violations of warranty provisions weighed heavily in the decisions. Thus, opportunity at a given installation was a primary factor affecting the sampling

Table 2. Summary of the field inspections of USAF EPDM roofs

| Air Force Installation | EPDM Roofs Inspected | Building Type | Manuf Code | Age mos | Membrane Securement | Sample Taken |
|---|---|---|---|---|---|---|
| Cannon, NM | 3 | Lean-To | J | 75 | Adhered | No |
| | | Lean-To | J | 75 | Adhered | No |
| | | Lean-To | J | 75 | Adhered | No |
| Chanute, IL | 1 | Hospital | -[a] | 85 | Ballasted | No |
| Eielson, AK | 10 | Office | - | - | Ballasted[b] | No |
| | | Dormitory | - | - | Ballasted[b] | No |
| | | Hangar | - | - | Ballasted[b,c] | No |
| | | Post Office | - | - | Ballasted[b] | No |
| | | Mess | - | - | Ballasted[b] | No |
| | | Dormitory | - | 156 | Ballasted[b] | No |
| | | Warehouse | - | - | Ballasted[b] | No |
| | | Paint Shop | - | - | Ballasted[b] | No |
| | | Dormitory | - | - | Ballasted[b] | No |
| | | Automotive | - | - | Ballasted[b] | No |
| Elmendorf, AK | 4 | Office | A | 108 | Adhered | No |
| | | Dormitory | -[d] | 108 | Ballasted[b] | No |
| | | Commissary | I | 54 | ballasted[b] | No |
| | | Hangar | J | 50 | Adhered | No |
| King Salmon, AK | 3 | Boiler | F | 37 | Adhered | Yes[e] |
| | | Fire Hall | E | 12 | Adhered | No |
| | | Storage | F | 23 | Adhered | No |
| Loring, ME | 4 | Shop | F | 24 | Ballasted | Yes |
| | | Mess | B | 12 | Ballasted | Yes |
| | | Shop | B | 11 | Ballasted | Yes |
| | | Quarters | B | 20 | Ballasted | No |
| New Boston, NH | 4 | Office | D | 60 | Adhered | Yes |
| | | Office | D | 60 | Adhered | No |
| | | Shop | D | 60 | Adhered | Yes |
| | | Shop | D | 60 | Adhered | Yes |
| Offutt, NE | 6 | Plant | A | 16 | Adhered[f] | No |
| | | Operations | E | 38 | Adhered | No |
| | | Base Exchg. | E | 44 | Adhered | No |
| | | Club | E | 18 | Adhered | Yes |
| | | Office | E | 19 | Ballasted | Yes |
| | | Chapel | E | 17 | Ballasted | No |
| Pease, NH | 2 | Operations | A | 84 | Ballasted[b] | No |
| | | Operations | A | 24/12[g] | Adhered | Yes |
| Pittsburgh IAP | 4 | Club | A | 96 | Adhered | No |
| | | Hangar | E | 68 | Adhered | No |
| | | Hangar | E | 68 | Adhered | No |
| | | Avionics | A | 96 | Ballasted | No |
| Reese, TX | 1 | Runway Ctrl | - | 60 | Adhered | No |

Note: footnotes are given at the end of the table which continues to the next page.

Table 2. Summary of the field inspections of USAF EPDM roofs (cont.)

| Air Force Installation | EPDM Roofs Inspected | Building Type | Manuf Code | Age mos | Membrane Securement | Sample Taken |
|---|---|---|---|---|---|---|
| Scott, IL | 6 | Office | A | 36 | Adh/Ballst[h] | No |
| | | Gym | A | 24 | Ballasted | No |
| | | Hospital | A | 108 | Adhered | No |
| | | Club | E | 12 | Adhered | No |
| | | Quarters | - | 3 | Ballasted | No |
| | | Operations | A | 48 | Ballasted | No |
| Whiteman, MO | 5 | Fuel Shop | L | 28 | Adhered | No |
| | | Fuel Shop | L | 40 | Adhered | No |
| | | Office | L | 28 | Mech. Fast. | Yes |
| | | Office | L | 28 | Mech. Fast. | Yes |
| | | Gym | L | 24 | Adh/Fast[i] | No |
| Wright-Patt, OH | 4 | Museum[d] | - | 108 | Adhered | No |
| | | Office/Mess | E | 12 | Adhered | No |
| | | Operations | - | 72 | Adhered | No |
| | | Operations | E | 24 | Adhered | No |
| Youngstown, OH | 4 | Hangar | A | 86 | Ballasted | No |
| | | Mess | - | - | Adhered | No |
| | | Office | A | 12 | Adhered | No |
| | | Club | - | 16 | Adhered | No |

[a]The dash indicates that the information was not available.
[b]This ballasted system was a protected membrane roof.
[c]In addition to the protected membrane section of the roof, the EPDM rubber was applied to vertical surfaces and roof support members.
[d]There was a question whether this roof contained EPDM.
[e]The membrane was marked and samples were taken after the visit.
[f]This roof also contained some areas of ballasted membrane.
[g]This building had two sections with membranes of different age.
[h]This building had two membranes, one adhered and one ballasted.
[i]This building had two roof sections, one adhered and the other mechanically fastened.

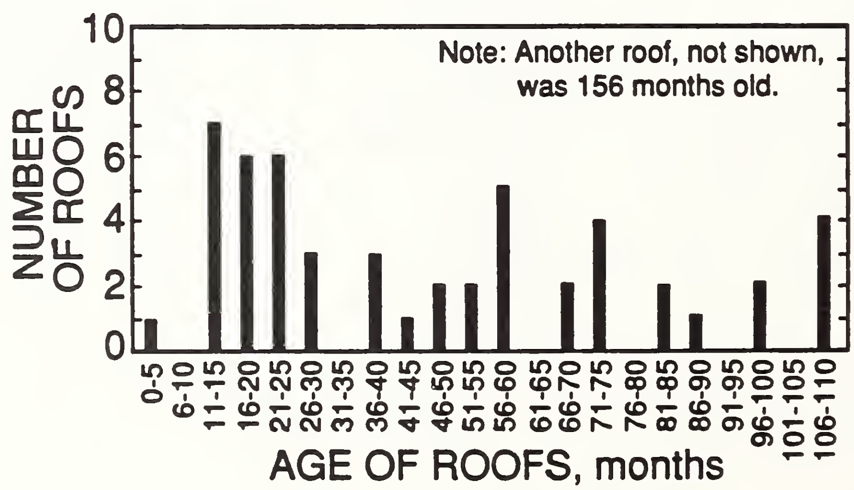


Figure 2. Number and age of the USAF EPDM roofs inspected

Table 3. General Comparison of Field Findings With AFESC Data File

| Air Force Installation | Number of Roofs File | Number of Roofs Found | Comments on Performance: Given In File | Comments on Performance: Field Findings[a] |
|---|---|---|---|---|
| Cannon, NM | 5 | 3 | ---[b] | NA |
| Chanute, IL | 1 | 1 | problem noted | adequate |
| Eielson, AK | 12 | 72 | performing well | adequate |
| Elmendorf, AK | 8 | 5 | problems noted | not adequate |
| King Salmon, AK | 3 | 3 | no maintenance | adequate |
| Loring, ME | 4 | 4 | no maintenance | adequate |
| New Boston, NH | 4 | 4 | good performance | not adequate |
| Offutt, NE | 13 | 13 | --- | NA |
| Pease, NH | 2 | 2 | no problems | adequate |
| Pittsburgh IAP | 2 | 4 | problem noted for 1 roof | not adequate |
| Reese, TX | 1 | 1 | no problems | adequate |
| Scott, IL | 5 | 7 | no maintenance | adequate |
| Whiteman, MO | 1 | 8 | --- | NA |
| Wright-Patt, OH | 6 | 8 | no repairs | not adequate |
| Youngstown, OH | 1 | 4 | no maintenance | adequate |

[a]The descriptor in this column indicates whether the comments given in the AFESC data file were considered to reflect adequately the performance of the roofs as observed during the field inspections.
[b]The dashed line indicates that no comments were given in the file. Consequently, a comparison to the field experiences was not applicable (NA).

process, and not necessarily performance considerations such as age of the roof, environmental conditions, or the type of membrane securement. Cutting of the EPDM membrane to observe components within the interior of the roof system was not done unless seam samples were taken.

## 3.2 Field Experiences Versus the AFESC Data File

The observations from the field inspections regarding the number of EPDM roofs at the USAF installations visited and performance of the roofs were compared with the expected findings, as based on the review of the AFESC data file. This comparison (Table 3) allows for comment on the reliability of the data file for indicating the status of EPDM roofing at the field installations. Note that the comparison regarding comments on performance is qualitative, and uses the terms "adequate" and "not adequate" to describe the data file.

At only seven of the 15 installations was the number of EPDM roofs in the AFESC data file equal to the number in place. At six locations, more EPDM roofing was found than was indicated in the file. Two main reasons accounted for this discrepancy. In some cases, roofs of new constructions having EPDM membrane systems were built by the Corps of Engineers. Such constructions were beyond the scope of the AFESC experimental roofing program. Thus, they were not included in the AFESC data file, and annual field reports concerning performance were

not submitted by USAF field personnel. In other cases, field personnel were generally satisfied with EPDM roofing, and wished to increase its use on buildings under their control. At times, they arranged for its installation without either asking the AFESC for a waiver from the BUR management program, or did not update the AFESC data file after receiving the waiver to use EPDM. The most notable example of a discrepancy between the AFESC data file and the field findings was Eielson AF Base. Here, 72 EPDM roofs were in place, but only 12 were recorded in the file. Seventy-two roofs represents more than 50 percent of the EPDM roofs indicated in the AFESC file.

Two installations were found to have less EPDM roofing than listed in the file. In one case, an adhered EPDM membrane system with mechanically fastened insulation was prematurely replaced because of wind damage. In another case, the building was razed. The records in the data file for these two roofs were not updated to show the changes. At one installation, it was discovered that roofs listed in the AFESC file as EPDM systems had BUR membranes. In one of these instances, the mislabeled roof was described in the file as having had leaks.

With regard to the comments on performance of the EPDM roofing, as discussed above, the descriptions in the AFESC data file indicated that performance was generally satisfactory. As is evident from Table 3, it was judged that such descriptions adequately reflected performance at a majority of the installations visited. In contrast, at four installations, the file comments on performance did not adequately reflect the field observations. In two cases, the file comments indicated good performance, but the field inspections found problems. In two other cases, although the file noted that problems had occurred, the comments understated their extent. It is also noted that, for two of the installations (Cannon and Whiteman), no comments were given in the file, but problems were observed with some of the roofs.

### 3.3 Discussions with Field Personnel

During the visits to the installations, discussions were held with field personnel to learn their experiences with EPDM roofing. It was not surprising to hear that most of these individuals were satisfied with the performance of EPDM, because many of them had submitted the comments on performance that were in the AFESC data file. Even at some installations where problems had occurred, the field personnel did not consider them to be so severe that they discouraged the use of EPDM. Thus, most of the field personnel urged the development of an USAF guide specification for EPDM roofing to provide them liberty in selecting alternative types of low-sloped roofing.

The major concern voiced by field personnel was the maintenance and repair of EPDM roofs. Many stated that they are not adequately knowledgeable about inspection procedures, and suggested that training methods for proper inspection of EPDM roofing by USAF personnel be developed. In a related matter, many field personnel raised concerns that they could not perform satisfactory routine maintenance or even emergency repairs to the EPDM roofs, because they

had neither the training nor the materials. Consequently, they urged that such methods be developed for the field installations, particularly if the use of EPDM increases with the development of a guide specification. Most installations indicated that permanent repairs to the EPDM roofs are performed by contractors although, in a few cases, in-house repairs are made.

In discussing maintenance of the EPDM roofs, field personnel provided mixed reports as to the frequency of inspections. Most indicated that they were committed to making annual surveys and submitting the data forms to the AFESC. Some also admitted that, under certain circumstances, pressing needs regarding the maintenance and operation of the facilities took priority over the reporting, or even the inspections of the roofs. In a few cases, field personnel stated that the roofs were only inspected when reports of leaks were received from building occupants.

### 3.4 Factors Affecting Performance

3.4.1 Membrane Material Weathering. A prime performance requirement for any low-sloped roofing system is that the membrane be durable and sustain the environmental stresses to which it is subjected over its intended service life. EPDM rubbers are described as having satisfactory weather and heat resistance, although these properties depend on the formulation of the EPDM product [11,12]. During the inspections, the surface condition of the EPDM rubber was examined, where possible, for signs of deterioration such as cracking, crazing, or extreme abrasion. Also, in lieu of testing, in a very rough manner, the general flexibility of the rubber was subjectively judged by pushing, pulling, or bending it by hand, particularly where wrinkles were present, or seam samples were cut. The intent was to see if there were any indications of embrittlement under the temperature conditions of the inspections.

Fifty eight of the membranes inspected were black. The subjective examinations of these materials did not indicate unacceptable weathering of the EPDM rubber. No signs of surface defects such as cracking or crazing, nor indications of embrittlement were apparent. Membrane defects such as punctures and splits were seen (as discussed later), but they appeared to be due to factors associated with the use of the roof or its design.

Three of the roofs inspected (Cannon AF Base) had white EPDM membranes. They were all installed at the same time by a single contractor who may have used the same lot of membrane material. Some surface cracking or crazing of the membranes was observed, but no indications of excessive embrittlement were found. The depth of the cracking or crazing defects into the rubber surfaces was not determined, because samples were not obtained for laboratory analysis. The membranes were functioning satisfactorily according to field personnel who indicated no leaks attributable to the surface condition. These roofs should be closely examined during maintenance inspections to determine whether the condition of the membrane surfaces is stable or changing.

3.4.2 Seams. A critical factor affecting the performance of EPDM rubber membranes is the integrity of adhesive-bonded seams. For example, results of NRCA "Project Pinpoint" surveys have pointed to seam defects as being the key concern regarding the performance of these single-ply membrane systems [3]. Consequently, during the roof surveys, considerable discussion was held with USAF field personnel regarding this performance factor. At the majority of the installations, their comments on the subject were favorable. In summary, most field personnel considered that the seams of the EPDM membranes had performed satisfactorily, and that few repairs to the seams had been required. In many cases, the type of adhesive used in the seams was not known. At two installations, discussions with field personnel indicated roofs that had experienced significant problems with seams, as discussed below.

Inspections of the roofs where the seams were exposed showed that most of the seams appeared to be intact and tight. Figure 3 shows a seam typical of many seen during the inspections. In general, the seams showed few deficiencies such as edge delaminations or fishmouths. The interior portions of the seams could not, obviously, be inspected to assess their condition without cutting the membrane or delaminating the seams. In conducting the inspections, the edges of many seams were probed with the tip of a blunt blade to determine whether the seam edge offered significant resistance to delamination. This was generally the case, but the use of such a rough technique to probe seams emphasized the need for reliable nondestructive methods.

Figure 3. A seam typical of many that were observed during the study

Seam problems at one building were attributed to material deterioration; at two other buildings, they were ascribed to unacceptable workmanship during installation. In the former case, seams having an adhesive reported by facility personnel to be neoprene-based[3] had deteriorated, as shown in Figure 4. This roof was about 4 years old when the problem first arose. In this case, the adhesive was seen to have delaminated from the rubber, lost cohesive strength, and taken on a mushy consistency. This observation was consistent with field experiences in that seams with neoprene-based adhesives have, in some cases, deteriorated after some years in service [13,14]. Technical reports describing the problem, its extent, and factors contributing to its occurrence have not been published in the roofing literature. One short review [14] on the effect of moisture on roof system performance stated that "neoprene cements that joined individual sheets and were used as flashing cements were sensitive to elevated temperature and water."

A notable aspect of the deterioration of the seams having the neoprene-based adhesive was that it did not occur randomly over the entire roof. On the contrary, it was confined to one section, which comprised not more than 25 percent of the roof area. Moreover, patches placed over the original deteriorated seams also experienced delamination. The adhesive for the patches was also reported to be neoprene-based. To the extent that it could be determined without delaminating seams that appeared to be functioning well, the seam

Figure 4. Delaminated seam having neoprene-based adhesive

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[3]Neoprene is the common term used to describe polychloroprene rubber, and is the nomenclature used in this report.

problem was not apparent for most of the roof area. Also, there was no evidence that the environment of the problem section of the roof was any different from that of the other areas. This raised a question whether some undetermined factor, other than the adhesive itself and perhaps its general environment, was playing a major role in the deterioration.

In the second case of seam problems, two roofs at the same installation (and applied by a single contractor under the same contract) that had experienced major problems; the seams contained numerous fishmouths and ripples. This was considered to be due to unsatisfactory workmanship, although the possibility that the EPDM sheets were not adequately flat or rectangular (which could have lead to ripples in their installation) could not be ruled out. Many of the ripples, but not all, bridged the entire width of the seam, and were obvious sources of leaks (Figure 5). In addition, the adhesive in the seams was extremely thick (about 50 mil or 1.3 mm). During application, thick adhesive layers retain the solvent longer than thin layers and require longer open times before the sheet surfaces bearing the adhesive can be mated together [15]. The longer retention of solvent may lead to excessive swelling of the rubber at the edges of the sheets where seams are to be made. The swelling is manifested as ripples which could, in turn, be incorporated in the seams. An example of this observation is given in Figure 6, where it is evident that the rippling is essentially limited to the seam section of the membrane. Such ripples are sources of peel stress that may delaminate the seam bond and produce leaks [16].

Figure 5. Fishmouth bridging the seam

3.4.3 Patches. One of the questions that has arisen concerning EPDM roofing is the performance of patches made on rubber surfaces that have been exposed in service for some length of time [5]. The concern is whether aging of the rubber alters the surface in such a way that successful bonding becomes difficult. The present study provided an opportunity to obtain some qualitative information on patch performance, because a number of patches were observed during the inspections. However, data on important variables such as age of the membrane when patched, age of the patch at the time of inspection, type of adhesive used to bond the patch, and the cleaning procedure used to prepare the rubber surface were normally not available. Reasons offered by field personnel for patching included fixing leaks in seams, removing wrinkles incorporated in the membrane at the time of construction, and repairing damage to the membrane done either during or after construction.

As was the case for seams, the conditions of the majority of the patches observed in the study appeared satisfactory, as probed with the tip of a blunt blade to determine whether they could be readily raised from the membrane surface. Generally, this could not be done. Figure 7 shows two patches adjacent to the covered fasteners in a mechanically attached system. They had reportedly performed well for the two years they were in service. The appearance of these patches was typical of most observed, and few patches with deficiencies (i.e., sections or edges not bonded to the membrane surface) were seen. The most significant case was the previously-mentioned roof (Section 3.4.2) where the adhesive-bonded patches over seams having neoprene-based adhesive, had also deteriorated. Such deterioration of patch adhesive was also found at two other installations (Figure 8), but the phenomenon was limited to a single patch per roof.

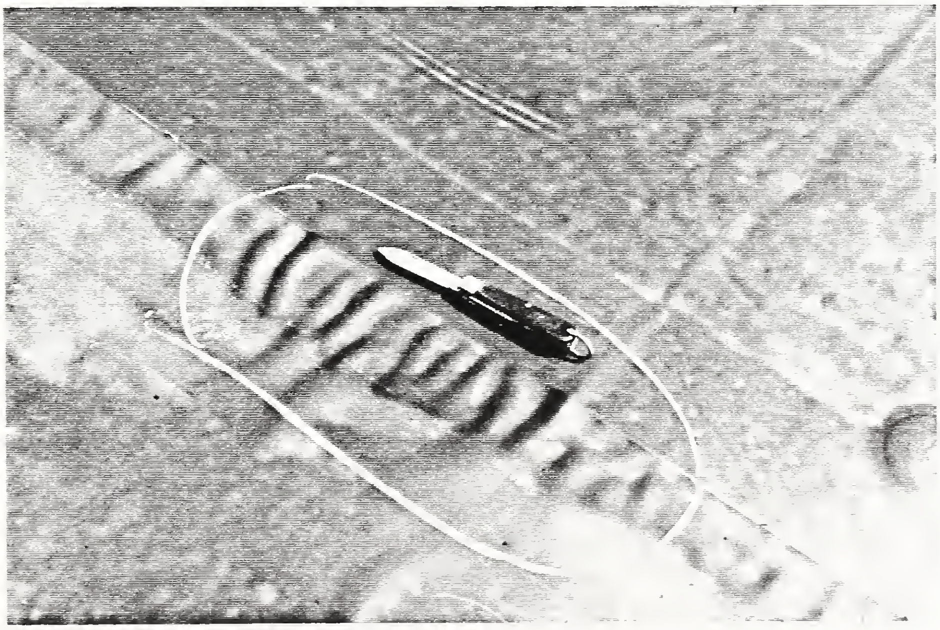

Figure 6. Ripples in the seam attributed to swelling of the rubber during adhesive application

Figure 7. Patches along side of a cover strip over mechanical fasteners; the patches had performed well

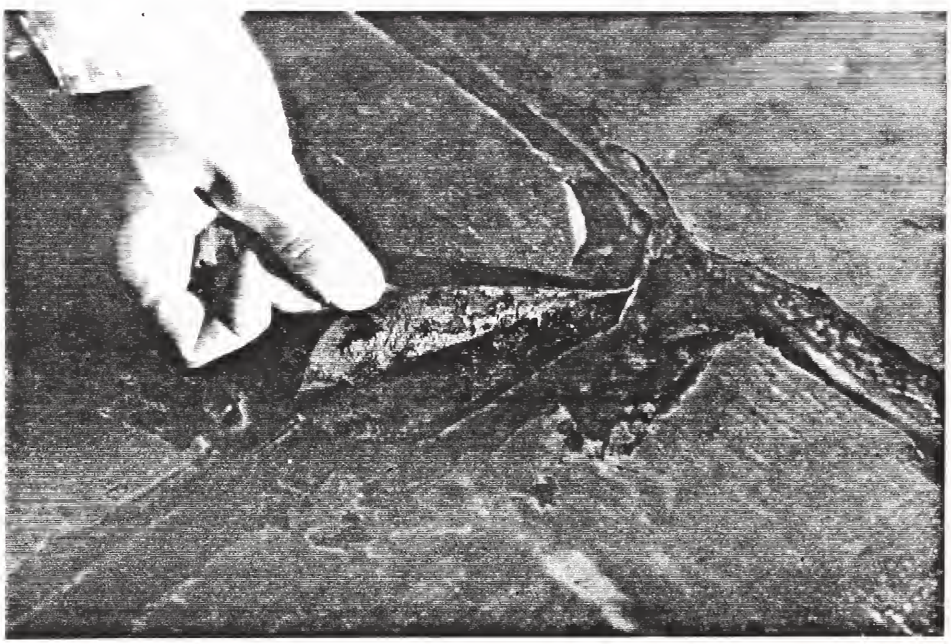

Figure 8. A patch with deteriorated adhesive; such observations were uncommon

3.4.4 Flashings. The rubber base flashings observed at penetrations and perimeters of the buildings were, with one exception, in generally good condition. A common deficiency, found on a number of roofs, was a limited section of flashing which was not sealed, but contained an opening or disbond, as illustrated in Figure 9. Reasons for these defects were not always apparent but, in some cases, it was considered that the flashings had not been properly sealed when constructed. Although the observations were limited, the findings of open sections of flashing illustrate the need for good periodic maintenance inspections, and the ability for inspectors to have timely repairs made.

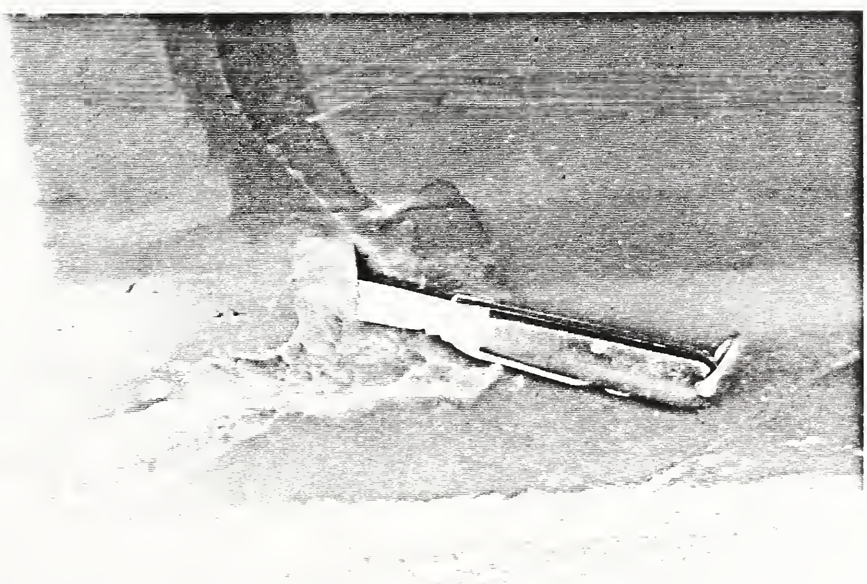

Figure 9. Small opening in a flashing; this was typical of many flashing defects observed

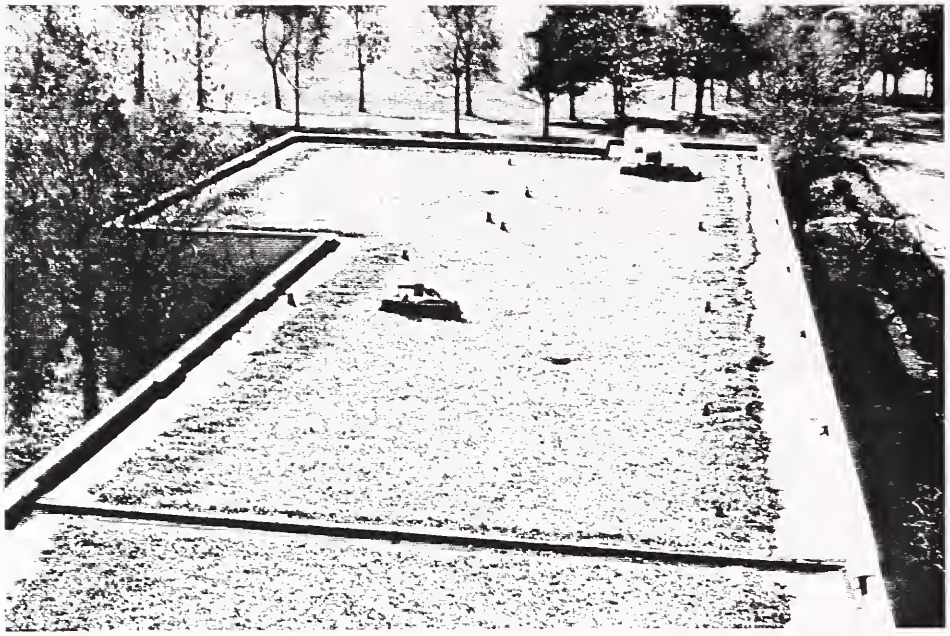

Figure 10. Roof with ballast swept back from the perimeter to allow ready inspection of the base flashing

At one installation, the perimeter base flashings of a ballasted membrane system were uncured neoprene-based rubber. This flashing material had cracked extensively and randomly over the entire perimeter area during the 7 years the roof had been in place. The problem was so extensive that the ballast had been swept back from the building perimeter to have all flashing areas visible for frequent inspection (Figure 10). Many of the cracks had been patched, although some were open to water penetration into the building. The cracks were limited in length, normally a few inches (centimeters) (Figure 11). They occurred at the edge of a wooden cant strip, where the flashing was stretched tight. Apparently, this produced excessive stress in the rubber at that location, which resulted in the cracks.

Maintenance personnel at this installation normally repaired the cracks in-house by covering them with patches. Most of the patches appeared to be in satisfactory condition, while some contained small cracks similar to those in the original flashing. It was indicated to NIST staff that plans were under development to replace the perimeter flashing, because of the extensive time spent in monitoring and repairing the flashing.

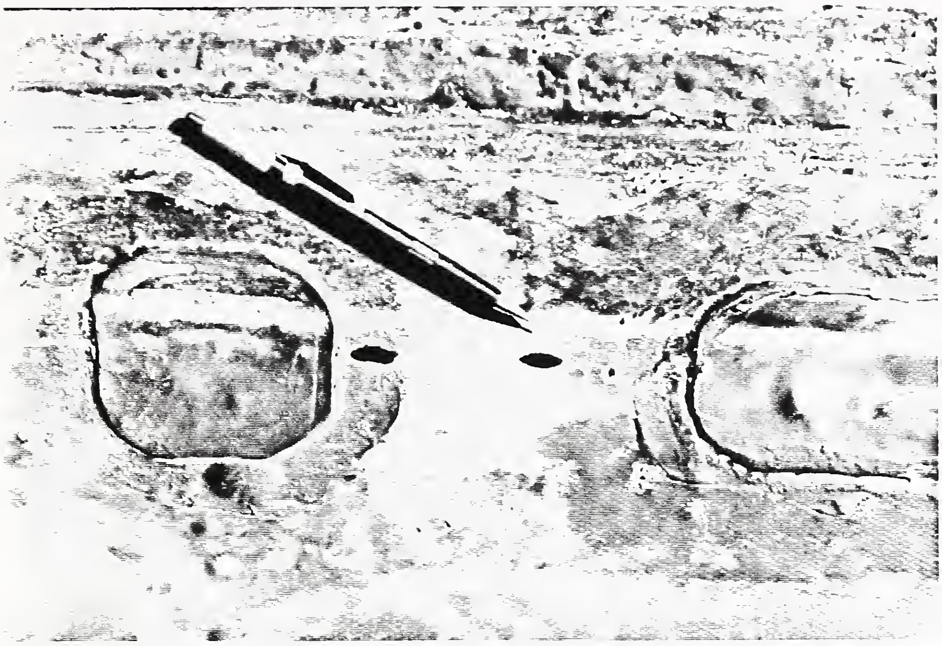

Figure 11. Cracks and patches in deteriorated base flashing

3.4.5 Securement -- Adhered Systems. Over half of the roofs inspected during the study contained an adhered membrane system. Securement of an adhered membrane depends on the adhesive bond between it and the substrate. Unfortunately, it is difficult to judge the adequacy of membrane bonding during a visual roof inspection. There may be no discernible signs to indicate whether the membrane is well bonded or not. A deficiency might only come to light in high winds. During walk-over roof inspections, only in circumstances such as sections of the adhered membrane being obviously loose on the substrate, might definitive evidence of inadequate securement be obtained. Standard methods for quantitatively assessing the extent of bonding between the membrane and its substrate are not available. Experience has shown that the securement of adhered membrane systems has generally been satisfactory. Inadequate securement of bonded membranes has not been singled out as a high-frequency defect of adhered single-ply systems [3]. An industry wind design guide has been developed for adhered single-ply roofing systems [17].

The results of the inspections of the adhered systems were positive, with no visual indications that membrane securement was inadequate. Figure 12 shows an adhered membrane system, typical of those inspected during the survey. The membranes generally appeared tight on the substrates with no evidence of loose areas. In the few cases where seam samples of adhered membranes were taken, the rubber sheets were seen to be well bonded to the substrates. Discussions of the performance of adhered systems with field personnel indicated that securement of the membrane had been satisfactory for most of the roofs. However, two significant anecdotes of wind damage to adhered membranes were reported.


Figure 12. A typical adhered-membrane system

In the first, an adhered membrane was placed directly on an existing BUR system on a barrel roof of a hangar. The existing BUR membrane was apparently granule-surfaced. During high winds (speed not indicated), a section of the membrane lost adhesion to the substrate and billowed extensively, but did not blow away. Figure 13 is a photo of the billowing taken during the wind storm, and made available to NIST during the field visit. A repair was made which involved slicing open sections of the loose membrane, re-adhering it to the substrate, and seaming the areas of the slices. When the roof was inspected, the repair had been in place 4 months during which high winds had not occurred. Field personnel were concerned that the billowing problem (or worse) might recur, since they had no means to assess the adequacy of the re-bonding of the membrane to the substrate. They asked whether a test procedure was available that was applicable to both the repaired section and the undamaged section of the EPDM membrane. Standard methods to assess the adhesion of the EPDM rubber to the surface of an existing membrane have not been developed. It is possible that the ASTM Method E 907, "Field Testing Uplift Resistance of Roofing Systems Employing Steel Deck Rigid Insulation and Bituminous Built-Up Roofing," may be applicable, because it provides a measure of the adhesion between components [18]. Data supporting its applicability to the EPDM adhesion question would need to be developed.

Figure 13. Billowing of the EPDM membrane on a hangar roof during a wind storm

A topic of discussion regarding the uplift problem with this hangar roof was whether the adhered EPDM membrane should have been installed directly on the existing BUR in the first place. If the existing BUR membrane was granule-surfaced, then direct adhesion of the EPDM rubber to the BUR membrane may have been imprudent. The adhesion of the granules to the BUR membrane surface may not have been adequate to resist the uplift forces on the EPDM in the wind storm.

The second report concerning wind damage to an adhered membrane system was sketchy, with few details on the occurrence available at the time of the NIST visit to the installation. In this case, it was reported by field personnel that an EPDM system (listed in the AFESC data file and considered for inspection during the study) had been replaced with a BUR membrane. As described, the EPDM experienced some degree of wind damage during a storm. The extent of the damage and factors contributing to it were not reported to NIST research staff, because field personnel present during the inspection where not responsible for the facility's roofs when the problem occurred. In any event, a decision was made at the time of the problem not to repair the EPDM system, but to replace it.

For many adhered systems, a number of observations were seen where fasteners used on insulation boards had apparently backed out and the fastener heads were pushing against the membrane. For the majority of the observations, puncturing of the membrane due to fastener backout had not occurred (Figure 14); however, in a few instances, it had (Figure 15). Backout of fasteners is a maintenance item for field personnel to consider during routine inspections.

Figure 14. Example of an isolated fastener that backed out from the deck; the membrane was not punctured

Figure 15. Example of an isolated fastener that backed out from the deck; the membrane was punctured

At one installation, the stress plates of mechanically fastened insulation in an adhered membrane system were set high on the top of the insulation boards (Figure 16). As a consequence, the membrane was stretched at the areas over the tops of the stress plates. In a limited, confined area (estimated to be about 10 %) of the roof, the membrane had split at the edges of some of the stress plates (Figure 17). The stretching of the membrane where the splits had occurred did not appear to be more extensive than that observed in areas without splits. Because the splitting was not random across the roof, a question was raised whether the membrane material in the areas of the splits was less resistant to stress cracking than that installed on the majority of the roof surface area. If such were the case, the risk of additional splitting occurring at other locations of the roof might be low. Nevertheless, periodic maintenance inspections should closely examine the membrane at each fastener stress plate to assure watertightness.

As a final point regarding adhered systems, the occurrence of wrinkles and ripples incorporated in the membrane during application is mentioned. For the majority of the roofs, wrinkles and ripples were essentially non-existent (e.g., Figures 3 & 10). However, for two roofs, they were found to be rather numerous (Figure 18). In these cases, no evidence of cracking of the rubber at these locations was found. However, if wrinkles and ripples occur in the area of seams (as discussed in Section 3.4.2), they produce fishmouths, and even if sealed tight, they subject the seams to peel stress [16].

Figure 16. Stress plates set high on the insulation boards

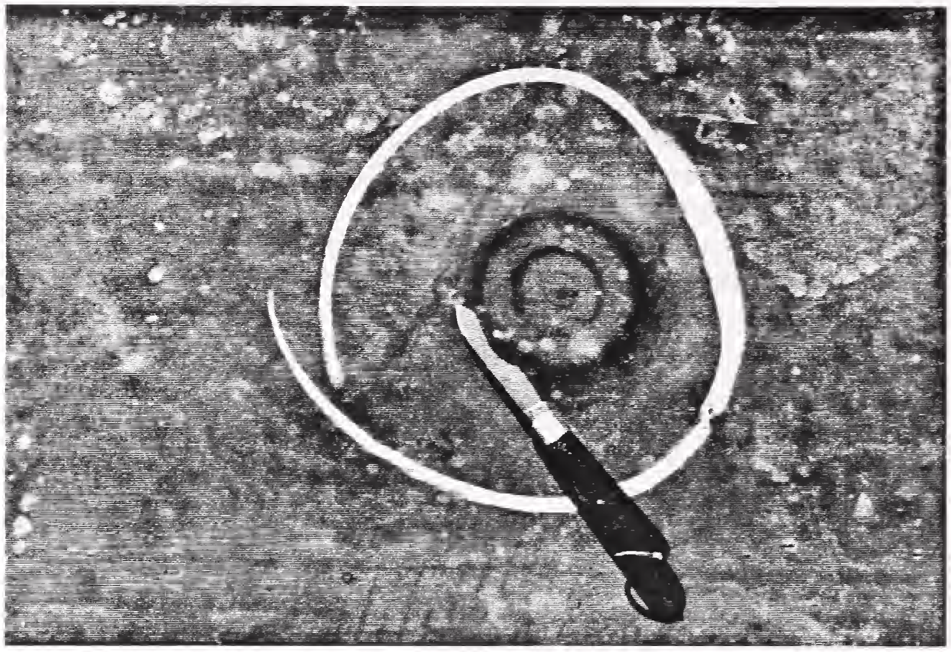

Figure 17. Split in the rubber membrane at the edge of a raised fastener stress plate

Figure 18. Area of an adhered system with a number of wrinkles in the membrane

3.4.6 Securement -- Ballasted Roofs. Fourteen of the roofs inspected, not including the protected membrane roof (PMR) systems, had ballasted membranes. The bulk of the information gained from a walk-over inspection of such roofing addresses the condition of the ballast and exposed flashings, since these may be the only components visible. The comments received from field personnel on the performance of the ballasted systems were positive with no problems reported.

The observations during the inspections were generally consistent with the comments received from the field personnel. Most of the ballasted roofs (excluding PMR systems) contained river-washed rounded stone. This stone ballast was seen to be evenly spread across the roof, and no signs of wind scour were present, even at the windward corners. The design guidelines by which the amount and size of the ballast were selected was not known. Industry guidelines for ballasted roofing are available [19]. For the roofs in the survey, in no case was the ballast at the corners (or perimeter) of the building seen to be of larger size than that in the middle field of the roofs.

At one installation, the ballast was a rounded stone that contained many fractured pieces, raising concerns that sharp edges were created on the stones. However, there were no indications that cutting of the membrane had happened, and leaks in the roof had not been reported. When fractured pieces of ballast were held in the hand, they gave no cause for concern that they could cut the skin. The observation of the fractured pieces, nevertheless, is a reminder that caution should be exercised in selecting ballast during roof design. The integrity of rounded stone should be considered. If it is felt that it cannot be maintained, then a protective mat should be installed between the membrane and ballast to guard against the fractured ballast puncturing or cutting the membrane.

Finally, four of the roofs (at two installations) from which seam samples were taken were ballasted. The ballast obviously had to be removed from the sample areas to expose the seams and allow patching of the cut membranes. At one installation, the roofing mechanics had plan-view drawings on which the seam locations were marked. Such drawings were not available at the second installation. Considerable time was saved in locating the seams of the roofs with the marked drawings. A valuable lesson was learned. Roofs having ballasted membranes should have the locations of the seams marked on an "as-built" roof plan. If the seams need to be located at a later date, time spent in searching for them will be saved.

3.4.7 Protected Membrane Roofing. Thirteen protected membrane roof (PMR) systems were inspected during the study. As for the normal ballasted systems, few features other than ballast and flashings were visible on these roofs. The majority of the PMR systems used concrete pavers as ballast. Experience has shown that some concrete pavers on PMR roofs have had poor freeze-thaw resistance [20]. In the present study, no signs of freeze-thaw deterioration of the pavers were observed.

For most of the PMR systems, the base flashings at the perimeters of the buildings were not visible. Figure 19 shows a section of a typical protected membrane roof with concrete pavers used as ballast in Alaska. Note the sheet metal covering obscuring the base flashing at the perimeter of the building.

With little visual evidence gained from the inspections of the PMR roofs, the prime source for information on their performance was the verbal reports from the facilities engineers responsible for their maintenance. With one exception, the PMR roofs inspected were installed in Alaska. Field personnel at these installations spoke positively about their performance, relating no incidence of major problems. Protected membrane roofing for cold regions has been the subject of considerable study by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and been shown to perform well in such locations [20]. Field personnel at the Alaska installations having PMR systems indicated that they were generally familiar with the CRREL research.

The most common defect mentioned by field personnel was leaks at flashings and penetrations, although it was pointed out that such problems had not been widespread for the roofs in question. Nevertheless, field personnel emphasized that even small leaks in PMR roofs are a costly maintenance problem, because of the difficulty in locating the sources of leaks under the ballast and insulation. In response to NIST questions regarding leaks at field seams in the EPDM PMR membranes, no incidence of such problems was reported.

Figure 19. A typical protected membrane roof with concrete pavers

The one PMR roof not in Alaska was located at Pease AF Base. This system was about 7 years old and used gravel as the ballast. Performance was described as being trouble-free. In this case, a "filter fabric" was present under the ballast to keep dirt and debris from washing under the insulation and into the drains. When inspected, no signs of concern were apparent, although the filter fabric had weathered and eroded away in some small areas where it was not covered with ballast. A limited length of a seam was inspected after removing a small section of ballast and insulation boards (Figure 20). As expected, dirt was present on the surface of the membrane. Some areas were damp to the touch, indicating that the seam may experience a relatively moist environment under the insulation boards which can retard drying [20]. As subjectively judged, the limited section of exposed seam appeared to be well bonded and tight, and was without ripples or other signs of distress.

A final note regarding this roof is that the seam exposed for inspection was difficult to locate. It was only found after making some guesses as to where it might be and carefully examining the base flashing at the perimeter of the building for signs that a seam was present. As previously indicated, the search for the seam was another reminder of the importance of having seam locations of ballasted systems marked on roof plans to eliminate needless time spent in finding them.

Figure 20. A seam of a protected membrane roof uncovered during the inspection

3.4.8 <u>Securement -- Mechanically Fastened Systems</u>. Only four of the roofs in the survey were mechanically fastened systems whereby both the membrane and insulation boards were secured with fasteners. One used batten bars which were about 4 ft (1.2 m) on centers. The other three were spot fastened with the fasteners generally 4 ft (1.2 m) on centers, except near the perimeter of the buildings where they were 2 ft (0.6 m) on centers.

For two of the four mechanically-fastened roofs inspected, field personnel were generally satisfied with the securement provided by the fastener system. Two of the spot-attached systems had experienced problems, one being significant as described below. Where fastener performance was described as satisfactory, the observations from the inspections were in accord. For the most part, the fastener installation appeared satisfactory (Figure 21), although a limited number of fasteners had backed out. Where fastener-backout occurred, it stretched, but generally did not puncture, the membrane. On one building, a line of fasteners had backed out as much as 6 in. (150 mm), stretching a patch that had been installed over the fasteners (Figure 22). In spite of the amount of stretching, the patch was not seen to be punctured. It was not known whether the original membrane under the patch had been punctured due to the fastener backout. As a general conclusion from the observations, fastener backout is an item that inspectors should pay close attention to during maintenance inspections, and initiate proper repairs where warranted.

Obviously, it was not possible during a visual inspection to obtain information on the hidden characteristics of the fastener systems. These would include aspects such as whether fasteners were overdriven into the deck, adequately penetrated the deck, misaligned on steel decks and driven into flutes instead of ribs of metal decks, or had poor pull out resistance. No examples of such hidden defects came to light in discussions with USAF field personnel. These aspects of fastener performance have been of interest to the roofing industry [21], and guidelines have been recently developed by the industry to assist in the design of mechanically attached single-ply roofing systems [22].

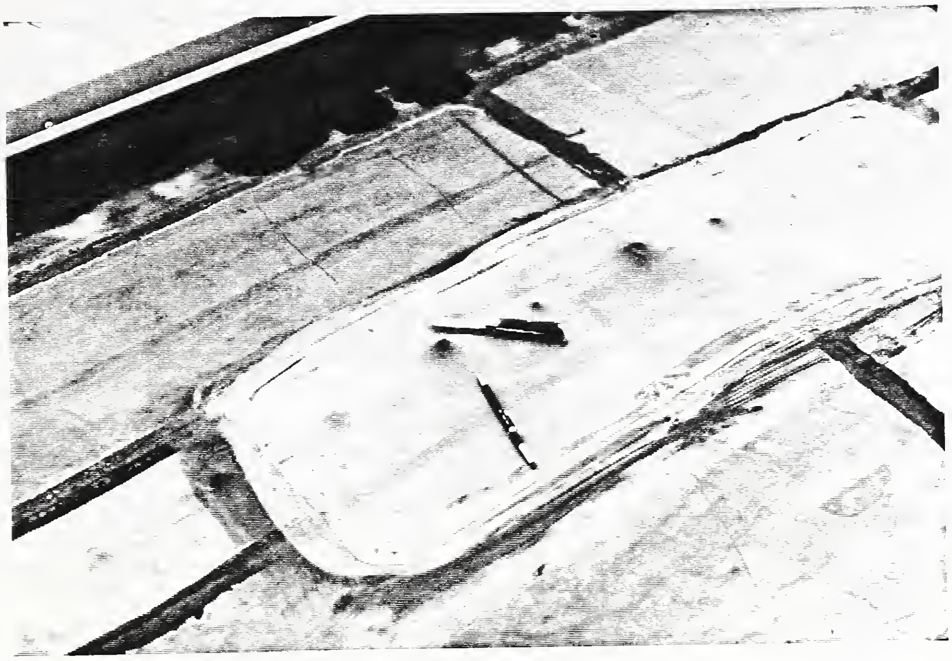

Figure 21. Mechanically-fastened system showing little fastener backout

Figure 22. Section of a patched seam where the fasteners had backed out as much as 6 in. (150 mm)

In the case of one of the mechanically fastened systems that was described as performing unacceptably, the cause was attributed to excessive fastener backout. The problem had occurred over a sufficiently large area of the roof that a contractor, called to investigate it, considered that high winds might extensively damage the membrane. Consequently, used automobile tires were placed on the roof as temporary ballast (Figure 23) until proper repairs and re-securement of the membrane could be made.

The mechanically fastened system in question used spot attachment in which each fastener was individually covered with a patch to seal the locations were the fasteners penetrated the membrane (Figure 23). In some locations on this roof, the fastener backout had been extensive enough to puncture the cover patches (Figure 24). The fastener backout had only occurred on the windward side of the building, about 10 to 20 ft (3 to 6 m) from the edge. Note in Figure 23 the position of the temporary ballast away from the edge of the building. It was at this location that the fastener installation pattern became less dense, switching from 2 to 4 ft (0.6 to 1.2 m) on centers. On the day of the inspection, a slight breeze occasionally blew. Whenever it occurred, sections of rubber membrane between the 4 ft (1.2 m) fastener spacing and in the area of the tire ballast stretched slightly and fluttered in the wind. Wind flutter resulting in fastener backout is known to occur in practice [23]. In the present case, the fluttering effect was not noticeable where the fastener pattern was 2 ft (0.6 m) on centers at the building edge where the fasteners had not backed out.

Figure 23. Used tires ballasting a section of a mechanically fastened system to provide temporary securement

Figure 24. A backed-out fastener which punctured the cover patch sealing the penetration

The second mechanically-fastened roof where field personnel indicated that they were not satisfied with the securement system was a spot-attached system of the type previously shown in Figure 23. In this case, the question of concern was not fastener backout, but proper sealing of the spots where the fasteners penetrated the membrane. For this system, as previously indicated, each fastener was individually covered with a patch to seal the penetrations. The concern was that many of the patches were not adequately centered over the fastener or adhered to the membrane. Figure 25 shows an off-center patch which provides little bond area on one side of the fastener plate. Figure 26 illustrates patches that were only partially adhered to the membrane. It was not known whether this latter condition resulted from unsatisfactory installation, or some disbonding of the patches after their installation. Field personnel stated that no leaks were reported in the field of the roof, indicating that the patches on the fasteners were functional in spite of the observed deficiencies. Repairs to off-center or partially disbonded patches are needed and close inspection of the system is required to assure that these patches continue to be watertight.

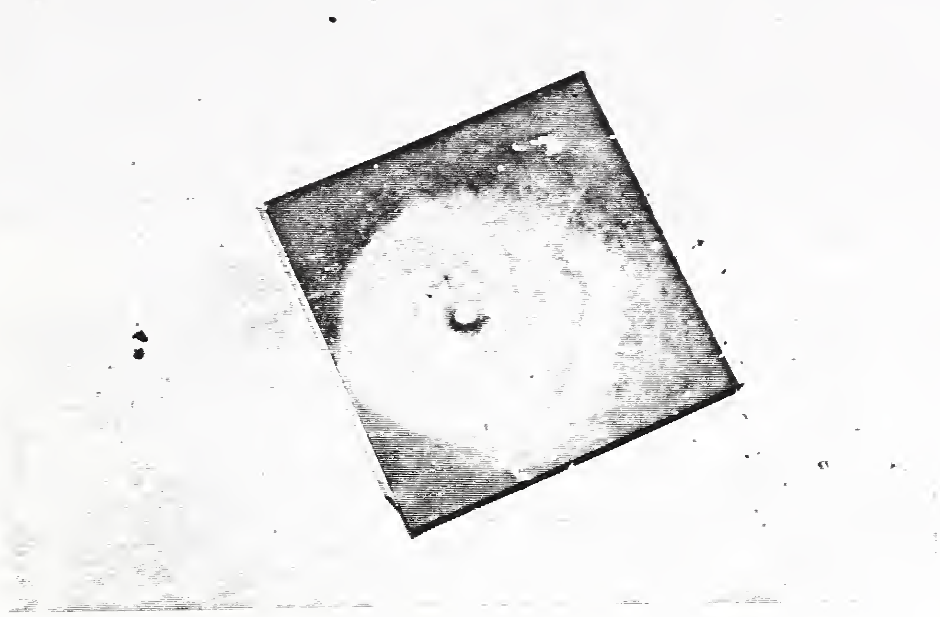

Figure 25. Off-centered patch over a fastener penetration; little bond area is provided on one side of the patch

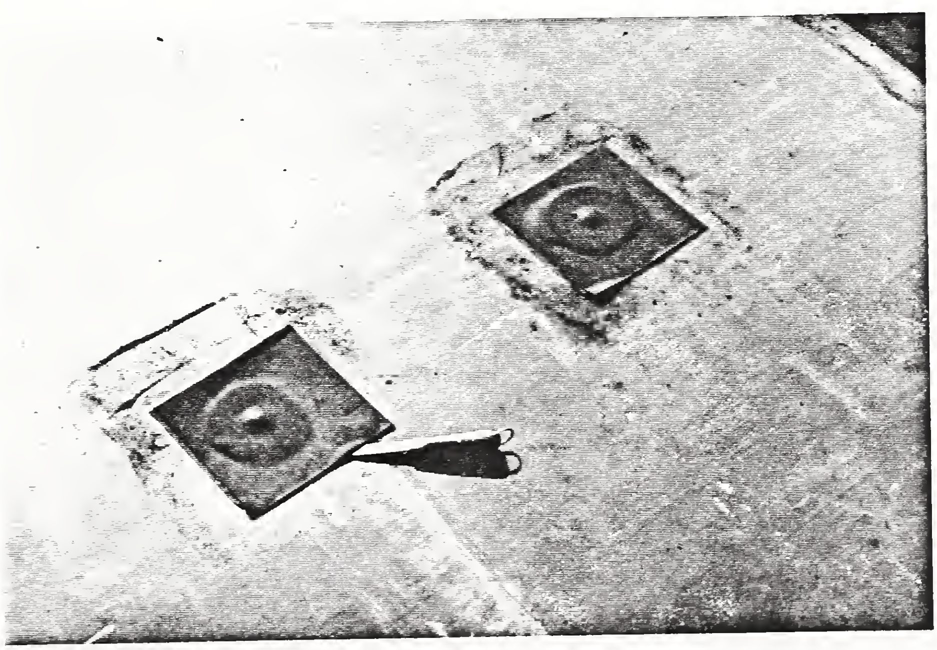

Figure 26. Lack of total adhesion of a patch over a fastener penetration

3.4.9 <u>Fastener Corrosion</u>. The question of corrosion of fasteners in low-sloped roofing systems has received considerable attention in the literature in recent years [21,24]. Fasteners have been observed to corrode in service, and depending upon the extent, loss of securement of the roofing system may result, making it vulnerable to damage in high winds. It has been difficult to establish the incidence of fastener corrosion because they are normally covered by the membrane [24]. Only when a membrane is cut in sections where fasteners are located are they observable.

Some observations, though limited, regarding the corrosion question were made during the study. Fasteners securing insulation in adhered systems were uncovered on three buildings (one observation in each case), when seam samples were cut from the membrane. These fasteners were not removed from the roofs, whose ages were 18, 24, and 60 months. In the three cases, no visual evidence of corrosion was found on the exposed fastener heads or stress plates (Figure 27). Also no evidence of excessive moisture (e.g., liquid water) was found in the insulation. Although extremely limited, the observations concerning fastener corrosion were consistent with the general findings of the NIST review of the fastener-corrosion question [24]. In the review, it was indicated that fastener corrosion has been generally found when a roof is wet, and not found when it is dry.

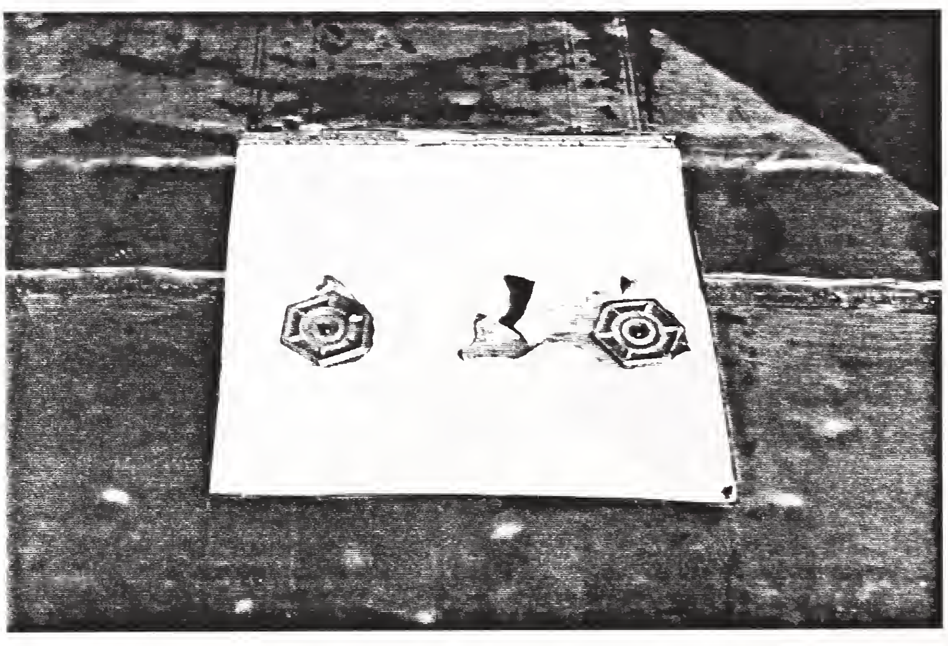

Figure 27. Fastener heads and stress plates uncovered during seam sampling; no corrosion was evidenced

3.4.10 Slope and Drainage. For the majority of the roofs inspected, sufficient slope was observed on the roofs (Figure 28), and the roofs generally drained well. Note in Figure 28 the extent of slope as indicated by the changing height of the parapet wall at the edge of the roof. In addition, where interior drains were observed, they were generally free of debris to provide unrestricted drainage. At one installation, the drain of an exterior gutter was blocked with leaves from an overhead tree. At another facility, an exterior gutter was clogged, but the source of the debris was unknown.

In spite of the generally good drainage, as might be expected, adequate slope did not exist over all sections of the roofs. In many cases, some areas showed indications of minor ponding, as evidenced by standing water or dirt deposited on the roof surface at locations where the water had collected and evaporated. Often, the minor ponding occurred along the edge of the roof, indicating that the slope in those locations was not sufficient. Figure 29 is an example of ponding along the roof edge. Perimeter details should consider sufficient slope to allow water to flow better over the roof edges.

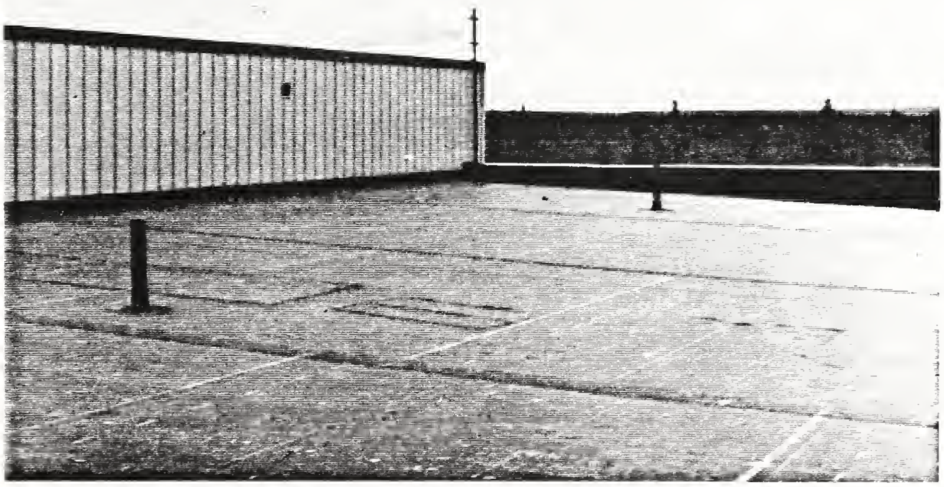

Figure 28. Illustration of the slope incorporated in many of the roofs inspected

Major ponding of water was observed for one building. This roof contained a paver-ballasted membrane which was essentially totally covered with water (Figure 30). The strainer of one drain was found to be clogged with debris, but its removal did not drain the roof. The roof needs to have all the drains closely examined to determine whether they are open or not. Undoubtedly, a leak in this roof would result in considerable water entering the building. With all the water present, it was not possible to judge whether sufficient slope was incorporated in the system. Note in Figure 30, however, that the height of the two parapet walls does not apparently change across the edges of the building. It was not known whether the ballast caused undue deflection of the roof, and thus contributed to the ponding. However, as is seen in Figure 30, the pavers were not continuous across the field of the roof. A question raised was whether the partial covering of the membrane surface with pavers was done because the roof could not sustain total coverage. This roof was 8 years old and had reportedly performed well over this time. Field personnel indicated that leaks, attributed to flashing problems where two sections of the building tied together, had occurred but were repaired. Since then, the roofing was reported to be leak-free.

Figure 29. Roof with generally adequate slope, except that ponding occurred along an edge

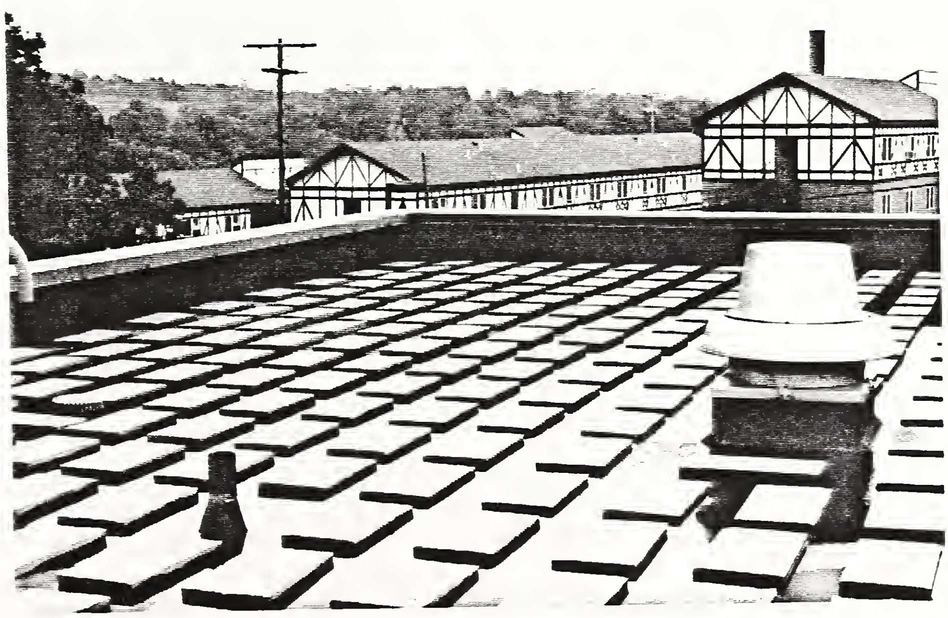

Figure 30. Extreme ponding of water on a ballasted system

3.4.11 <u>Abuse</u>. Abuse is any action or treatment of the roof which results in damage to the roofing system, and in particular, the membrane. Roof abuse was of concern to many of the field personnel at the installations visited, but the concerns were not specific to EPDM roofing. Many anecdotes were told of unauthorized use and abuse of all types of roofs which resulted in leaks. The most notable example was the installation of antennas. Interestingly, during this EPDM study, no examples of abuse due to antenna installation were observed.

For the roofs inspected, abuse was not seen to be a wide-spread problem for any one roof or collection of EPDM roofs at a single installation. Nevertheless, sufficient examples of damage from abuse were found to reiterate a general principal of good roofing practice that unauthorized traffic on the roof should be avoided. Collectively, the observed number of cases of abuse implies that a considerable effort must be expended to correct the damage done. Moreover, a disconcerting aspect of the examples of abuse was that the problems created had not been repaired, which enhances the opportunity for spreading water within the roof and building, and increasing consequential damages.

The cases of abuse to the EPDM roofing could be placed in one of two categories: (1) abuse associated with the use of the roofs, either authorized or unauthorized, and (2) abuse associated with improper maintenance. In the former category, the following examples are given:

- o small tears were seen in a membrane near a door to a second-story room housing mechanical equipment; the tears may have been caused by dragging equipment across the roof without protecting the membrane.
- o a small cut was apparently made (but not patched) in a membrane during a routine survey of the roof system for the presence of asbestos-containing materials.
- o a membrane contained a small puncture which was probably made from a tool dropped by someone doing equipment maintenance; this roof was inaccessible without use of high-reach equipment.
- o a hole, thought to be a burn of unknown origin, was seen on one roof.
- o a dart was found sticking into the membrane (Figure 31).
- o an eye hook, used to anchor a guy wire, was screwed through a membrane.
- o oil from mechanical equipment or grease from kitchen appliances were discharged directly on EPDM surfaces (Figure 32); the membranes were seen to be swollen due to the oil or grease. In the cases observed, it was noted that the swelling damage to the membrane was somewhat localized at the spot of the discharge. Apparently, neither flowing of the oil or its washing by rainwater spread the damage over large sections of the EPDM membrane. This suggested that lamination of an oil or grease resistant rubber to the EPDM membrane at the spot of discharge might prevent the local damage.

Figure 31. Example of abuse to an EPDM membrane; a dart was found stuck in its surface

Figure 32. Oil effluent from a ventilator swelling the EPDM rubber membrane

In the category of roof abuse being by improper maintenance, the following example is given:

- o the use of asphaltic mastic (plastic cement) as an intended repair material. This was found on isolated spots of four roofs (Figure 33), presumably in attempts to stop leaks. The solvents in these mastics swell EPDM rubber, similarly to the action of some oils discharged from equipment. In cases where mastic was observed, USAF engineering personnel accompanying NIST staff were aware that these solvent-bearing materials should not be used on EPDM. They considered that uninformed shop personnel used the mastics on EPDM in a repair manner that might be routinely done for bituminous roofing. The observations concerning the improper use of mastics illustrate the concerns expressed by field personnel that training and guidelines are needed for the maintenance and repair of EPDM roofing at USAF installations.

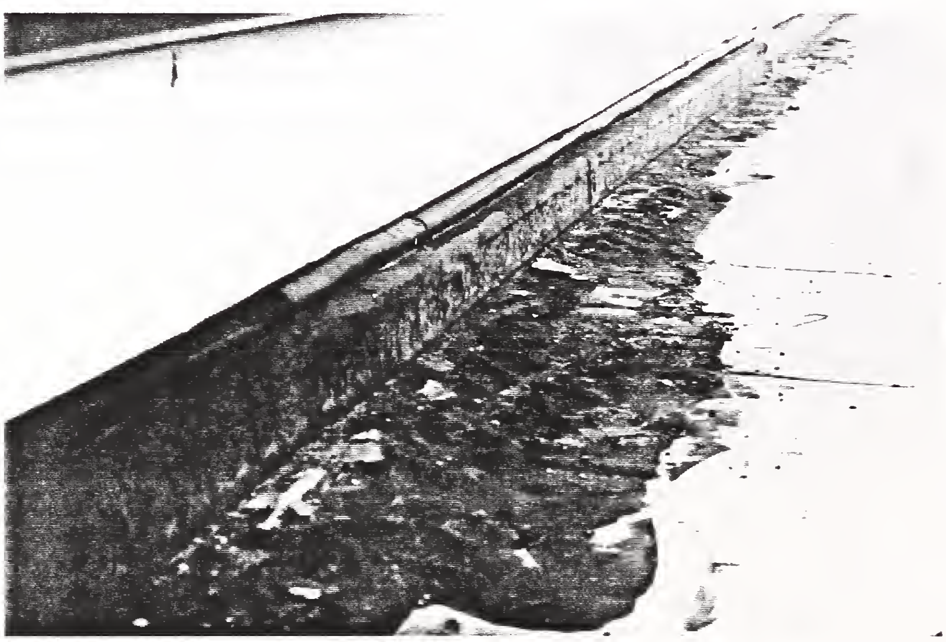

Figure 33. Swelling of the membrane due to the application of asphaltic mastic in an attempted repair

3.4.12 Pitch Pans. These are metallic pans placed around penetrations and filled with a sealant material to waterproof the penetrations. Historically, bituminous sealants have been used, but presently elastomeric sealants are employed for EPDM roofing to fill the pans. Figure 34 shows a pitch pan filled with elastomeric sealant. Good roofing practice has advised against the use of pitch pans because of the maintenance problems that they create. In particular, bituminous sealants have been prone to cracking and shrinkage which eventually result in leaks if the pans are not maintained full.

Few pitch pans were observed on the USAF roofs inspected. Where pitch pans were present, they were found to be full of elastomeric sealant which was crack-free and pliable to the touch (Figure 34). The ages of the roofs with the pitch pans ranged from 38 to 68 months. Routine maintenance should include pitch pan inspections to assure that they remain functional.

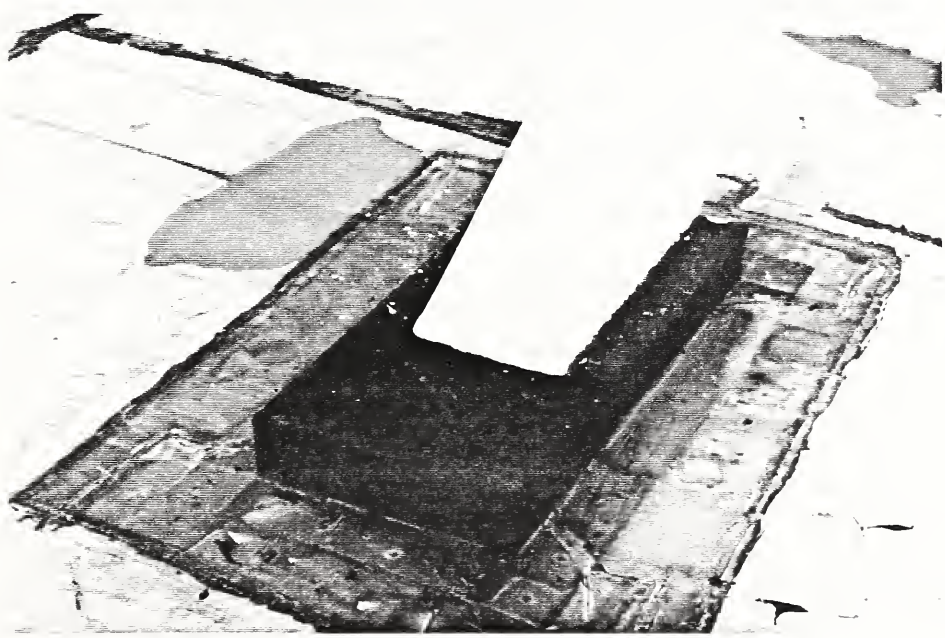

Figure 34. Pitch pan filled with elastomeric sealant

## 4. OVERALL PERFORMANCE OF THE ROOFS

A goal of the study was to provide a general assessment of the overall performance of EPDM roofing at the USAF installations. To this purpose, a numerical, though subjective, ranking system was devised for assigning a performance rating to the roofs inspected. This section of the report presents a summary of the individual ratings. The rating system devised was based on two factors: (1) the field observations made by NIST research staff (as discussed in the Sections 3.4.1 through 3.4.12), and (2) the discussions held with field personnel during the inspections. The ratings assigned to each roof ranged from 1 to 5, with 5 being the top classification. The basis for each numerical rating was as follows:

| Rating | Basis |
|---|---|
| 5 | No defects were observed; discussions with field personnel raised no major concerns with performance. |
| 4 | Defects, very limited in scope, were found on the roof; in these cases, it was considered that routine maintenance could readily repair the defects; or a condition was seen that had apparently not affected the functioning of the roof, but was considered to require close attention during future inspections; discussions with field personnel raised no major concerns with performance. |
| 3 | A number of defects were found on the roof; although numerous, it was considered that routine maintenance techniques could readily repair the defects; discussions with field personnel raised no major concerns with performance. |
| 2 | Significant defects were observed and were considered to require more than routine maintenance to repair them; discussions with field personnel raised major concerns with an aspect of the roof's performance. |
| 1 | Significant defects were found to the extent that replacement of the roof would be considered as a repair option; during discussions, field personnel raised major concerns with some aspect of the performance of the roof. |

The ratings assigned to each of the roofs were based on their condition as seen and discussed at the time of the inspection. For example, if a past repair (e.g., patch) had been made to a roof that was found to be performing satisfactorily, then the assigned rating reflected the current performance and did not consider that a repair

had been necessary. Also, minor ponding[4], which occurs on many low-sloped roofing systems, was not considered to be a defect in assigning the ratings. For one reason, although complete drainage is recommended as good roofing practice, minor ponding is not treated as a routine maintenance item for which some repair activity is needed.

A limitation of the devised rating system is that it considers only the observations made of the visible portions of the roof system. Extensive sampling of the roofing components to measure properties or evaluations to determine the presence and extent of moisture within the roofs was beyond the scope of the study.

The ratings were assigned after all inspections were completed and after careful review of the information obtained. Table 4 presents the assigned ratings to each roof. In two cases, ratings were not given because the field inspections indicated that the roofing may not have been EPDM.

Table 4. Performance rating assigned to USAF EPDM roofs

| Air Force Installation | Building Type | Rating | Major Observation Affecting the Assigned Rating |
|---|---|---|---|
| Cannon, NM | Lean-To | 4 | Localized surface crazing |
| | Lean-To | 4 | Localized surface crazing |
| | Lean-To | 4 | Localized surface crazing |
| Chanute, IL | Hospital | 2 | Deteriorated neoprene-based base flashings |
| Eielson, AK | Office | 5 | -- |
| | Dormitory | 5 | -- |
| | Hangar | 5 | -- |
| | Post Office | 5 | -- |
| | Mess | 5 | -- |
| | Dormitory | 5 | -- |
| | Warehouse | 5 | -- |
| | Paint Shop | 5 | -- |
| | Dormitory | 5 | -- |
| | Automotive | 5 | -- |
| Elmendorf, AK | Office | 4 | Puncture of the membrane |
| | Dormitory | - | Not rated; may not be EPDM |
| | Commissary | 5 | -- |
| | Hangar | 2 | Splits in membrane at edges of the fastener stress plates; concern about wind damage to the membrane |

[4]A definition of minor ponding does not exist in the roofing industry. It usually signifies a small section of the roof which holds some water for a relatively short period after a rainfall. Such ponding is sometimes called a "bird bath."

Table 4. Performance rating assigned to USAF EPDM roofs (cont.)

| Air Force Installation | Building Type | Rating | Major Observation Affecting the Assigned Rating |
|---|---|---|---|
| King Salmon, AK | Boiler | 4 | Punctures of the membrane |
| | Fire Hall | 5 | -- |
| | Storage | 4 | Minor seam repair needed |
| Loring, ME | Shop | 4 | Poor repair to a base flashing |
| | Mess | 5 | -- |
| | Shop | 4 | Loose guy wire at a vent stack |
| | Quarters | 4 | Potentially sharp ballast |
| New Boston, NH | Office | 2 | Excessive fishmouths in seams |
| | Office | 2 | Excessive fishmouths in seams |
| | Shop | 4 | Wrinkles in membrane & seams |
| | Shop | 3 | Many patches needed |
| Offutt, NE | Plant | 5 | -- |
| | Operations | 5 | -- |
| | Base Exchg. | 4 | Partially delaminated patch |
| | Club | 4 | Clogged gutter |
| | Office | 5 | -- |
| | Chapel | 5 | -- |
| Pease, NH | Operations | 4 | Open perimeter flashing |
| | Operations | 5 | -- |
| Pittsburgh IAP | Club | 4 | Clogged drain; grease on membrane near kitchen vent |
| | Hangar | 4 | Two small punctures |
| | Hangar | 2 | Seams delaminated |
| | Avionics | 2 | Excessive ponding |
| Reese, TX | Runway Ctrl | 1 | -- |
| Scott, IL | Office | 4 | Split in flashing |
| | Gym | 5 | -- |
| | Hospital | 4 | Oil swelling of membrane |
| | Club | 5 | -- |
| | Quarters | 5 | -- |
| | Operations | 5 | -- |
| Whiteman, MO | Fuel Shop | 4 | Minor seam repair needed |
| | Fuel Shop | 5 | -- |
| | Office | 2 | Considerable fastener backout |
| | Office | 4 | Minor fastener backout |
| | Gym | 3 | Many cover strips over mechanical fasteners need attention; small section of membrane with asphaltic mastic |
| Wright-Patt, OH | Museum | - | Not rated; may not be EPDM |
| | Office/Mess | 4 | Membrane puncture |
| | Operations | 4 | Area of open base flashing |
| | Operations | 4 | Some fasteners have backed out |
| Youngstown, OH | Hangar | 5 | -- |
| | Mess | 5 | -- |
| | Office | 5 | -- |
| | Club | 5 | -- |

A summary of the ratings is as follows:

| Rating | Number of Roofs | Percent of Total Roofs Rated |
|---|---|---|
| 5 | 28 | 47 |
| 4 | 22 | 37 |
| 3 | 2 | 3 |
| 2 | 7 | 12 |
| 1 | 0 | 0 |

In discussing the ratings, it should be remembered that the majority of the roofs were less than 5 years old (Figure 2). With consideration of this relatively young age, as is evident in the summary above, the overall performance of the EPDM roofs inspected at the USAF installations was considered to be satisfactory. Forty-seven percent were assigned a performance rating of 5, while 37 percent were given a rating of 4. That is, about half of the roofs were visually found to be in fine condition, while another third displayed only minor defects which were very limited in scope and were considered to be readily reparable with routine maintenance. For both categories, field personnel expressed no concerns about performance.

On a less positive note, most of the roofs with a 4 rating contained minor defects, which were in need of repair. It was felt that the repairs could, in general, be readily accomplished (at least on a temporary basis) if trained maintenance staff had repair materials, and took the time to perform the repairs. As previously indicated, a key concern expressed by field personnel is their lack of ability to perform routine maintenance. To reiterate a point made above, minor defects, left unrepaired for long periods of time, can lead to considerable water entry into the roofing, and thus, their consequences could be greater than if the defects were repaired when found.

Only two roofs (3 percent) were placed in the rating category 3. It was also considered that the defects in this case could be easily repaired by routine maintenance but, because they were more numerous, the repairs would be more time-consuming than those for category 4.

Seven roofs (12 percent) were considered to have defects beyond the type easily reparable by routine maintenance, and would require more extensive attention. These included:

- 3 roofs with seam problems
- 1 roof with deteriorated neoprene-based base flashing
- 1 roof with significant fastener backout
- 1 roof with small membrane splits around the edges of stress plates used with mechanical fasteners. This roof had also experienced wind damage to an adhered membrane and field personnel were uncertain whether the problem would recur.
- 1 roof with extensive ponding

None of the above problems are unique to the USAF. The four problems with seams and deteriorated neoprene-based base flashing are typical of EPDM roofing [3]. Wind and fastener problems are more associated with mechanically fastened single-ply systems, and not specifically EPDM [21]. And, finally, the one problem of extensive ponding of water has no association with any specific type of membrane, but is a function of slope and drainage of the low-sloped roof system.

## 5. LABORATORY TESTS OF SEAM SAMPLES

### 5.1 Samples

Table 5 presents, for each of the seam samples, the number of specimens, location of the building, membrane manufacturer, and membrane age. Thirteen samples with ages ranging from 11 to 60 months were obtained from six installations. Six manufacturers of EPDM roof systems were represented in the sample set. The majority of the seam samples were taken from roofs whose seams were found to be performing satisfactorily. Only in the case of seam sample nos. 4 and 5 was performance described as unsatisfactory.

Table 5. Seam data set

| Sample No. | Number of Specimens | Roof Location | Membrane Manufact. | Membrane Age, mos |
|---|---|---|---|---|
| 1 | 3 | Loring AFB | 1 | 24 |
| 2 | 3 | Loring AFB | 2 | 12 |
| 3 | 3 | Loring AFB | 2 | 11 |
| 4 | 3 | New Boston Air St. | 3 | 60 |
| 5 | 2 | New Boston Air St. | 3 | 60 |
| 6 | 2 | New Boston Air St. | 3 | 60 |
| 7 | 2 | Pease AFB | 4 | 24 |
| 8 | 2 | Pease AFB | 4 | 12 |
| 9 | 3 | King Salmon Air St. | 1 | 37 |
| 10 | 3 | Offutt AFB | 5 | 18 |
| 11 | 3 | Offutt AFB | 5 | 19 |
| 12 | 2 | Whiteman AFB | 6 | 28 |
| 13 | 2 | Whiteman AFB | 6 | 28 |

### 5.2 Results and Discussion

The test procedures used in the study are described in the Appendix. Table 6 summarizes the data and observations obtained during testing of the seam samples. Data were recorded in a computer file and analyzed using a graphics program called "DATAPLOT" [25]. For each specimen cut from a roof, five 4 by 1 in. (100 by 25 mm) strips were used in determining peel strength and adhesive thickness. Figures 35 and 36 are plots of the strength and thickness measurements, respectively. For the peel strength, the coefficient of variation within any one set of five strips was 25 percent or less whereas, between replicate sets for a given sample, it was 56 percent or less. Similarly, the coefficient of variation for adhesive thickness within any one set of five strips was 45 percent or less whereas, between replicate sets for a given sample, it was 37 percent or less.

Table 6. Seam Characteristics

| Smpl No. | Adhesive Type: Flame Color | Adhesive Type: FTIR[a] | Adhesive Thickness mm | Adhesive Thickness mil | Peel Strength kN/m | Peel Strength lbf/in | Peel Mode (percent) Adh | Peel Mode (percent) Coh | Peel Mode (percent) Void | Surface[b] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Orange | B | 0.13 | 5 | 0.28 | 1.6 | 94 | 0 | 6 | 2 |
| 2 | Orange | B | 0.13 | 5 | 0.23 | 1.3 | 82 | 0 | 18 | 2,3 |
| 3 | Orange | B | 0.10 | 4 | 0.56 | 3.2 | 71 | 0 | 29 | 2 |
| 4 | Orn/Gr[c] | B/N[c] | 1.3 | 52 | 0.40 | 2.3 | 46 | 25 | 29 | 1,2 |
| 5 | Orange | B | 1.5 | 60 | 0.49 | 2.8 | 47 | 31 | 22 | 1,2,3 |
| 6 | Orange | B | 1.5 | 57 | 0.60 | 3.4 | 52 | 24 | 24 | 3 |
| 7 | Orange | B | 0.20 | 8 | 0.42 | 2.4 | 1 | 68 | 31 | 1 |
| 8 | Green | N | 0.08 | 3 | 0.30 | 1.7 | 87 | 0 | 13 | 1,2 |
| 9 | Orange | B | -- | -- | 1.0 | 5.9 | 9 | 49 | 42 | 1,2 |
| 10 | Orange | B | 0.13 | 5 | 0.46 | 2.6 | 77 | 0 | 23 | 2,3 |
| 11 | Orange | B | 0.10 | 4 | 0.54 | 3.1 | 78 | 0 | 22 | 2,3 |
| 12 | Orange | B | 0.10 | 4 | 0.63 | 3.6 | 0 | 70 | 30 | 1 |
| 13 | Green | N | 0.10 | 4 | 0.21 | 1.2 | 100 | 0 | 0 | 2 |

[a]B and N indicate that the FTIR spectrum of the sample was typical of a butyl-based or neoprene-based adhesive, respectively.
[b]Visual characterization of the surfaces after peel test: 1 = no obvious contamination on the adhesive; 2 = no obvious contamination on the rubber; 3 = some contamination noted.
[c]The adhesive layer exposed upon delamination of the seam specimen showed a section colored black and a section colored yellow. The flame test and FTIR analysis was conducted on each section. The black adhesive gave results typical of butyl, whereas the yellow gave results typical of neoprene.

The values for peel strength and adhesive thickness given in Table 6 are the averages of all determinations (i.e., number of specimens times five). Average values were used for simplicity in reporting and graphically illustrating the results.

Identification of the type of adhesive in the seam sample was based on a comparison of its Fourier Transform Infrared (FTIR) spectrum with spectra of known butyl-based or neoprene-based products. The "Beilstein Flame Test" (Appendix A) was conducted as a rapid screening procedure for the presence of neoprene-based adhesive (a chlorine-containing polymer) before performing the FTIR analysis. Whenever the color of the flame was described as green, the FTIR spectra indicated that the adhesive was neoprene-based.

The majority of the adhesives were found to be butyl-based. This was not unexpected considering that butyl-based adhesives came into considerable use in the mid-1980s [26], and the ages of the samples did not exceed 60 months. Two of the adhesive samples (nos. 8 & 13) were neoprene-based. In case of sample no. 4, one of the replicate specimens had an adhesive layer that contained a section of butyl-based adhesive and another of neoprene-based adhesive (Table 6).

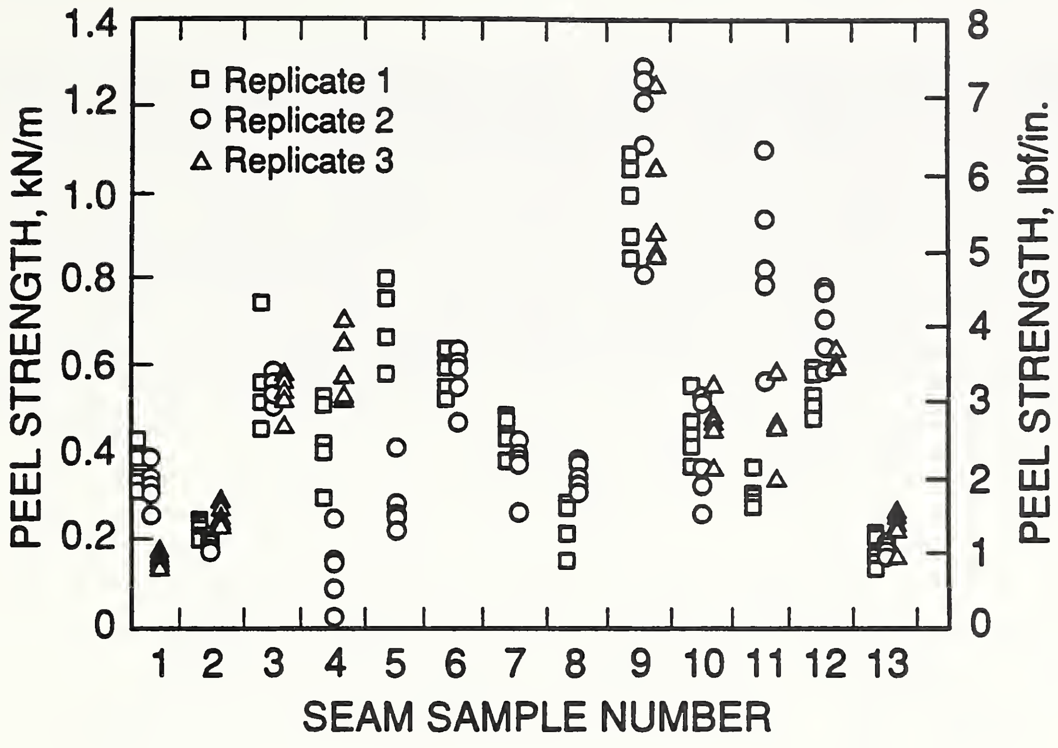


Figure 35. Peel strengths of seam samples

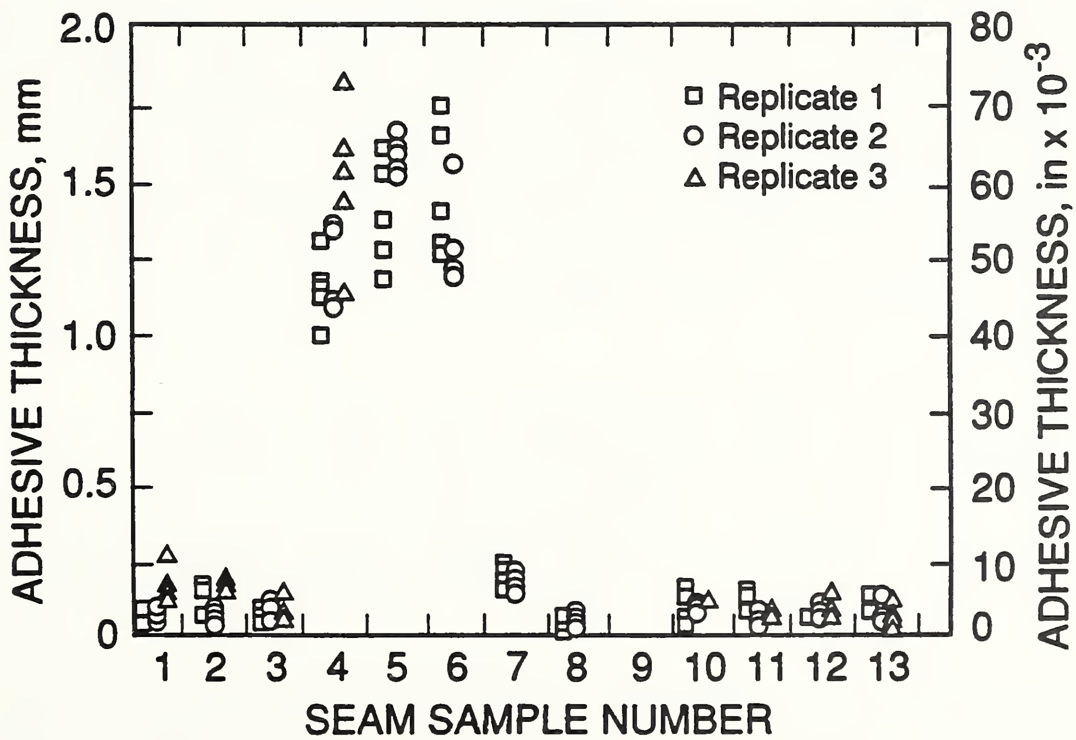


Figure 36. Adhesive thicknesses of seam samples

Sample no. 4 was taken from an adhered membrane system. Some contamination of the seam with neoprene-based adhesive used to adhere the EPDM membrane to the substrate may have occurred.

Figure 37 is a plot of peel strength versus sample age. No relation between these two parameters was found. The strengths of the samples ranged from 1.2 to 5.9 lbf/in. (0.21 to 1.0 kN/m). This range of values was comparable to those measured for other field-fabricated seams [27]. Generally, butyl-based seams have strengths greater than neoprene-based seams [28]. In the present study, the strengths of two of the butyl-based samples (nos. 1 & 2) were similar to those of the two neoprene-based seams (nos. 8 & 13).

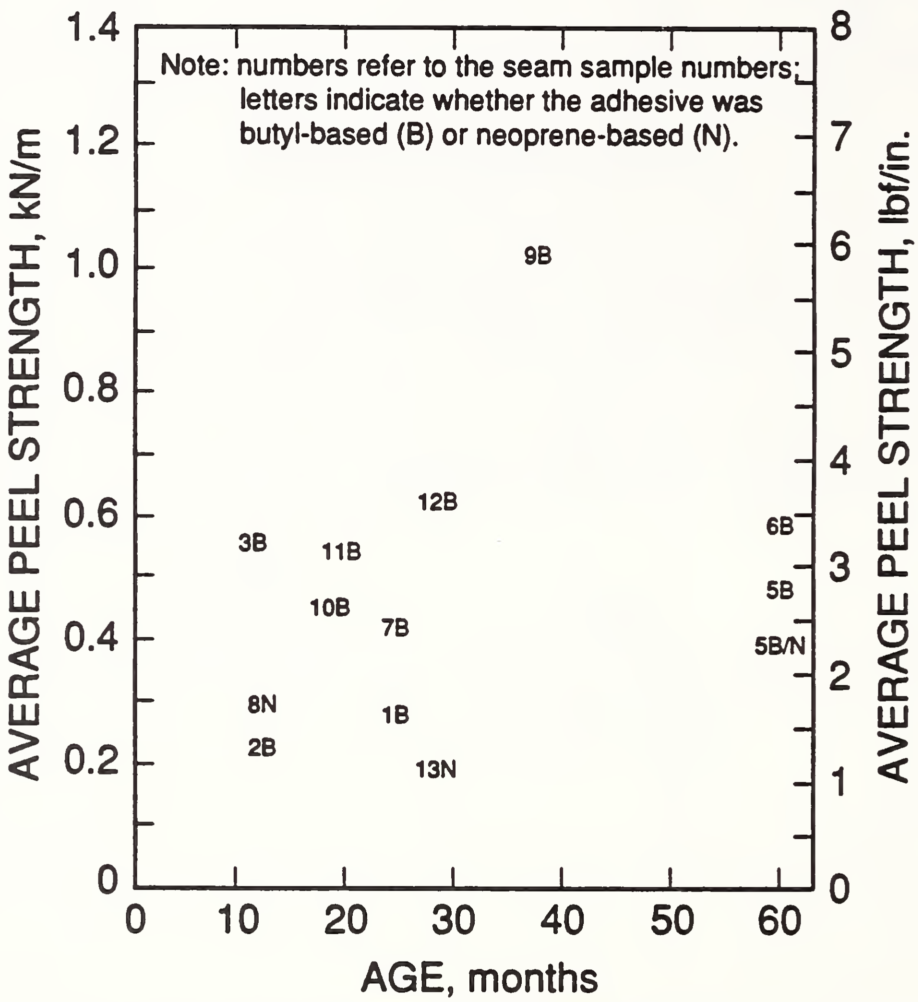


Figure 37. Average peel strength versus seam sample age

With the exception of the seam samples from New Boston (nos. 4 - 6), the thicknesses of the adhesive layers were 0.008 in. (0.20 mm) or less (Table 6). These values were comparable to adhesive thicknesses found for other field-prepared seams, and have been considered to be relatively thin [27]. Seams having relatively thin adhesive layers may not be as resistant to peel failure under creep conditions, as they could be if they had thicker adhesive layers [16].

The New Boston samples (nos. 4 - 6) had extremely thick adhesive layers, ranging from 0.052 to 0.060 in. (1.3 to 1.5 mm). The seams of two of these roofs (nos. 4 & 5) had not performed satisfactorily, which was attributed to the excessive fishmouths and wrinkling of the membrane at the laps. The relatively thick adhesive layers may have contributed to the formation of the fishmouths and wrinkles, because of the retention of solvent during seam fabrication. As previously discussed, laboratory experimentation has shown that the time required for the evaporation of the adhesive is lengthened (> 1 hour) when the layer is thick, which can result in considerable swelling of the membrane sheet [15].

Seams fabricated from butyl-based adhesive and EPDM rubber having cleaned surfaces normally fail cohesively in peel tests [29,30]. In the present study, the major mode of peel failure for the majority of the butyl-based samples was adhesive (interfacial). This indicated that surface effects were playing a role in the peel strengths of the samples. In general, the exposed surfaces of the delaminated peel samples were visually found to be free of contaminants. Five samples (Table 6) showed limited contamination on some, but not all, of the strips tested in peel. These contaminants included dust, particles typical of release agent, pieces of an aluminum foil typical of insulation board facer, and an oily film.

Scanning electron microscopy (SEM) was conducted on one seam sample from each of the six installations where samples were taken. The major observations from the SEM analyses were that:

- Adhesive and rubber surfaces exposed due to interfacial failure during peel testing showed the presence of platelet particles indicative of release agent. These contaminants would contribute to relatively low peel strength of the joint and, in the case of butyl-based adhesives, peel failure of the adhesive/rubber interface [15,24]. The observations of release agent on all adhesive and rubber surfaces exposed by adhesive failure of the joint were similar to those of another field study [27]. The finding provides evidence that a field method to judge rubber surface cleanness before application of the adhesive is needed.

- Some specimens showed the presence of micro-cavities within the adhesive layers. Such observations have been made during previous SEM analyses of field specimens, and attributed to volatilization of residual solvent in the adhesive at the time of seam formation [27]. These micro-cavities may be considered as defects in the adhesive layer which would contribute to lower-than-expected peel strength of the bond when failure is cohesive (and the micro-cavities were not present).

## 6. LESSONS LEARNED

Based on the results of the inspections and discussions held with field personnel, a number of lessons were learned which the USAF should bear in mind in developing its guide specification for EPDM roofing. The lessons learned are presented in this section of the report.

| Performance Factor | Lesson Learned |
|---|---|
| 1. Overall Performance | 1. The majority of the USAF EPDM roofs have performed satisfactorily. This observation must consider that the roofs were relatively young, and that the assessment did address the hidden interior portions of the systems (either by cutting or NDE methods). Where observed, many defects were considered reparable by routine maintenance action. |
| | 2. Many field personnel are satisfied with EPDM roofing and welcome the development of a guide specification. |
| | 3. Where major deficiencies were seen, they were not unique to the USAF. Attention to proper design, construction and maintenance of EPDM roofs should reduce the risk of such problems occurring. |
| 2. Maintenance | 1. In the case of many of the roofs, few maintenance activities (outside of inspections) have been necessary. In other cases, the defects observed were readily reparable by routine maintenance action. |
| | 2. Many of the readily reparable defects were found unrepaired. Timely repair of such defects is necessary to prevent an increase in the consequential damages caused by water entry into the roof and building. |
| | 3. Many field personnel emphasized that they are uneasy about their ability to inspect and maintain EPDM roofs. They desire more training and improved guidelines for maintenance. The CERL "Handbook for Repairing Nonconventional Roofing Systems" [31] has been provided to all installations. |
| | 4. Many field personnel realize that they are limited in making routine or emergency repairs to EPDM roofing. A key concern expressed is the lack of kits for making such repairs. |

| Performance Factor | Lesson Learned |
|---|---|
| 3. AFESC Data File | 1. In general, the data file indicated a trend of satisfactory performance of EPDM roofs at many USAF installations, which was consistent with the field observations. In specific cases, examples were found where the data file did not reflect the observations from the inspections. |
| 4. EPDM Weathering | 1. The black EPDM membrane materials appeared to be weathering well; no alarming signs of distress to the contrary were found. |
| | 2. In a limited observation, three white membranes (installed at the same time by the same contractor) showed some surface cracking and crazing. |
| 5. Seams | 1. Again considering the relatively young age of the roofs, the seams generally performed well; in one case, seams having neoprene-based adhesive had significantly deteriorated over a section of roofing. |
| | 2. Major seam problems at two roofs were attributed to excessive fishmouths and wrinkles in the seam; it is essential that proper workmanship be exercised in the formation of seams. |
| | 3. NDE Methods are needed to assess the condition of seams; for this critical performance parameter, a walk-over roof inspection does not allow an assessment of the interior portions of seams. |
| | 4. A field method to judge rubber surface cleanness before application of the adhesive is needed; limited observations of adhesive and rubber surfaces exposed due to interfacial failure during peel testing showed the presence of platelet particles indicative of release agent. |

| Performance Factor | Lesson Learned |
|---|---|
| 6. Patches | 1. Patches appeared to be performing well; however, important information concerning factors such as the method of cleaning the membrane surface before application of the patch were not available, and thus, the lessons learned here are limited. |
| 7. Flashings | 1. In general, flashings appeared to be in good condition. |
| | 2. Limited sections of some flashings contained an opening or disbond. Reasons for these defects were not always apparent, but in some cases, it appeared that the flashings had not been properly sealed when constructed. |
| | 3. Sound periodic maintenance inspections are needed, and inspectors must initiate timely repairs. |
| | 4. Undue stressing of uncured flashing materials should be avoided during installation to reduce the risk of their splitting. |
| 8. Securement of Adhered Systems | 1. In general, no signs of inadequate securement were observed, but two problems of wind damage were reported. A standard field method is needed to assess the adhesion of adhered membranes to their substrates. |
| | 2. Maintenance inspections should watch for backout of mechanical fasteners used to secure insulation boards in these systems; when found, such defects should be repaired in a timely manner to avoid puncture of the membrane. |
| 9. Securement of Ballasted Systems | 1. These roofs had performed well; no signs of wind scour were apparent. |
| | 2. A roof plan of the completed system should note the locations of seams in the membrane. |

| Performance Factor | Lesson Learned |
|---|---|
| 10. Protected Membrane Roofs | 1. These roofs generally performed well; when leaks occurred, flashings were described as their main source.<br><br>2. Care should be exercised in installation of these roofs; field personnel expressed much concern with the difficulties in locating leaks under the insulation and ballast.<br><br>3. As was indicated for ballasted roofs, a plan of the completed system should mark the locations of seams in the membrane. |
| 11. Securement of Mechanically Fastened Systems | 1. These roofs had generally performed well; the main deficiencies were due to fastener backout.<br><br>2. It is essential that the design and application of these systems consider the numerous factors that affect performance such as the type of fastener, their spacing, and the workmanship exercised during installation.<br><br>3. Close attention to fastener backout is needed during maintenance inspections; when found, such defects should be repaired in a timely manner. |
| 12. Fastener Corrosion | 1. For the very limited observations made, no evidence of corrosion was observed; in these cases, the insulation was felt to be dry. |
| 13. Slope and Drainage | 1. Most roofs had adequate slope, and drained well; one extreme case of ponding was observed.<br><br>2. Not unexpectedly, minor ponding, often at sections of the perimeter, was observed. |

| Performance Factor | Lesson Learned |
|---|---|
| 14. Abuse | 1. Abuse of the EPDM roofs was not found to be an extensive problem at any one Air Force installation; however, sufficient examples were collectively seen to cause concern that considerable effort needs to be expended to correct the damage done. |
| | 2. Unauthorized use of the roofs and improper maintenance procedures should be avoided; in particular, maintenance personnel should be instructed (or reminded) not to use asphaltic mastic on EPDM rubber. |
| 15. Pitch Pans | 1. The limited number of pitch pans having elastomeric sealant were full, free of cracks, and pliable to the touch; routine inspections of these roofs should include the pitch pans to assure that they remain functional. |

## 7. SUMMARY AND CONCLUSIONS.

This study was conducted at the request of the U.S. Air Force to obtain and analyze information on the in-service performance of low-sloped EPDM roofing systems at USAF installations. The Air Force has considered that benefits are to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems. The data obtained contribute to the technical database needed to support the development of a proposed USAF guide specification for EPDM roofing.

Fifteen USAF installations in 11 states were visited, and 61 EPDM roofs were inspected to observe firsthand the performance of these systems. The age of the roof systems ranged from 3 to 156 months, although 40 percent were 30 months old or less. The inspections were performed by walking over the roofs during which notes were recorded and photos were taken. A limitation to the inspections was that the observations were made only of the visible portions of the roof system. A limited number of seam samples were taken to conduct laboratory tests for their characterization. During the visits, discussions were held with field personnel to determine their views of the performance and maintenance requirements of EPDM roofing under their responsibility.

Three key conclusions from the study are as follows:

- Considering the relatively young age of the roofs inspected, their overall performance was found to be satisfactory. About half were visually seen to be in fine condition, while another third displayed only minor defects which were very limited in scope and were considered to be readily reparable with routine maintenance.

- Where reparable minor defects were observed, they had gone without repair. This illustrated a key concern expressed by field personnel that they are limited in making routine or emergency repairs to EPDM roofing.

- NDE methods are needed to assess the condition of seams; for this critical performance parameter, a walk-over roof inspection does not allow an assessment of the interior portions of seams.

## 8. ACKNOWLEDGMENTS

This study was conducted under the sponsorship of the U.S. Air Force, Air Force Engineering and Services Center (AFESC), Tyndall Air Force Base, Florida. The encouragement, support, and assistance of Dennis Firman, Julian Ius, and Robert Marcy of the AFESC were greatly appreciated.

The authors extend special thanks to the USAF field personnel for their valuable contributions in arranging the visits to the installations and in assisting with the roof inspections. These individuals who gave freely of their time and hospitality are:

Jack Bach
Melissa Bartell
John Crow
Hilton Culpepper
Al Darnaby
Dan Eckert
Ruthanne Flottman
Bruce Foster
Del Jackson
Chris Lease
Gordon Mattzella
Claude Mayer
Richard Millard
Gordon Moore
Jeff Neilsen
Scott Newquist
Dennis Pardee
Jeff Ray
Frank Rosa
Mark Stillmock
Roy Thomas
Oscar Valdez
George Van Slyke
Pete Vlahavas
Phil Wright

The authors also acknowledge with thanks the support of their NIST colleagues: Willard Roberts and Eric Byrd (Center for Building Technology) for assistance in conducting FTIR analyses, Geoffrey Frohnsdorff, Larry Masters and Robert Mathey (Center for Building Technology) for reviewing a draft of this report, and James Lechner (Center for Applied Mathematics) for data reduction and analysis. The authors also thank Christopher Hodges, Law Engineering, Chantilly, VA, for his valuable contributions in reviewing a draft of this report.

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# APPENDIX A. EXPERIMENTAL PROCEDURES FOR SEAMS

## A.1 Samples

The dimensions of the samples were about 450 x 300 mm (18 by 12 in.) with the seam oriented parallel to the long dimension. The width of the seams ranged from about 75 to 150 mm (3 to 6 in.). It was planned to obtain a minimum of three specimens for each seam sampled. However, in four cases, practical constraints associated with cutting seams from roofs in service precluded sampling three replicates.

## A.2 Test Procedures

All adhesives were subjected to a "Beilstein" flame test and an FTIR analysis for identification of the generic type. For the adhered seam samples, the peel strength and adhesive thickness were measured, and the mode of failure during peel testing was noted. Three failure modes were apparent: adhesive (interfacial), cohesive, or through small void areas present in the adhesive layer. The surface of the voids was shiny as if little or no contact of the adhesive had occurred in these areas. Although the voids produced a "cohesive-like" failure, they represented a distinct failure mode and were distinguished from cohesive failure. For most samples, the failure during peel testing was a combination of two or three of the modes. A rough estimate ($\pm$ 10%) was made of the percent of the seam surface area experiencing each of the failure modes. After peel testing, the surfaces of the delaminated strips were closely examined by eye to assess whether any contamination could be seen on the exposed rubber or adhesive. A selected number of delaminated strips were examined using scanning electron microscopy (SEM).

A.2.1 T-peel Tests. T-peel tests were conducted according to the procedure described in ASTM D 1876, "Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)" [A1], except that the load was applied at a constant rate of 50 mm/min (2 in./min). The length of the bond delaminated was approximately 100 mm (4 in.). The testing machine was equipped with a microcomputer which was used to calculate the average peel force per unit specimen width.

A.2.2 Adhesive Thickness. The adhesive thickness was estimated for each sample as follows. Before peel testing, the thickness of the specimen was measured at two locations (about 25 mm or 1 in. from each end) using calipers sensitive to 0.0025 mm (0.0001 in.). The thickness of the rubber sheet comprising the seam was determined at four locations, also using the calipers. The adhesive thickness was the difference between the average thickness of the specimen and that of the rubber sheet, and estimated to be $\pm$ 0.05 mm ($\pm$0.002 in.).

A.2.3 Beilstein Flame Test of the Adhesives. A classical qualitative analysis procedure for the identification of halide-containing organic compounds is the "Beilstein Test" [A2]. A small sample of the adhesive compound, scrapped from the surface of the EPDM sheet after delamination of the seam, is burnt on a piece of copper using a laboratory gas flame. If a halide is present, a green flame is produced.

A.2.4 Fourier Transform Infrared Thermography (FTIR). The adhesive (about 50 mg) was placed in a test tube to which toluene (2 mL) was added. The test tube was sealed with a cork and gently shaken by hand. It was placed in a water bath at about 65°C (149°F) for 3-4 h over which time it was occasionally shaken by hand. Not all the adhesive always dissolved, but sufficient amounts went into solution to cast a film of the adhesive on NaCl crystals. FTIR transmission spectra were obtained using the coated crystals.

A.2.5 Scanning Electron Microscopy (SEM) Analysis. The specimens for SEM analysis were cut from delaminated seam samples into squares having about 8 to 10 mm (0.3 to 0.4 in.) sides. The cut pieces were adhered to SEM specimen mounting stubs with an epoxy adhesive. The mounted specimens were sputter coated with a nominal 20 nm ($8 \times 10^{-7}$ in.) gold conductive film to prevent surface electron charging during SEM analysis. The surfaces were examined in the SEM using an acceleration voltage of 10 kV at magnifications from x20 to x1000. Photographs were generally taken at x100 and x500 magnifications.

A.2.6 Appendix References.


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| NIST-114A (REV. 3-90) | U.S. DEPARTMENT OF COMMERCE<br>NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY<br><br>**BIBLIOGRAPHIC DATA SHEET** | 1. PUBLICATION OR REPORT NUMBER<br>NISTIR 4504<br>2. PERFORMING ORGANIZATION REPORT NUMBER<br><br>3. PUBLICATION DATE<br>JANUARY 1991 |
|---|---|---|

**4. TITLE AND SUBTITLE**

A Field Study of the Performance of EPDM Roofing at Air Force Facilities

**5. AUTHOR(S)**

Walter J. Rossiter, Jr., James F. Seiler, Jr., William P. Spencer, and Paul E. Stutzman

**6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)**

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

**7. CONTRACT/GRANT NUMBER**

**8. TYPE OF REPORT AND PERIOD COVERED**

**9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)**

U.S. Air Force
Air Force Engineering and Services Center
Tyndall Air Force Base
Tyndall, FL 32403

**10. SUPPLEMENTARY NOTES**

**11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)**

A study was conducted at the request of the Air Force Engineering and Services Center to obtain and analyze information on the in-service performance of low-sloped EPDM roofing systems at Air Force installations. Because of the benefits to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems, the Air Force has proposed developing a guide specification for EPDM roofing. Technical data are needed to support the development of the guide specification. The information obtained in the study contributes to the data base.

Fifteen USAF installations in 11 states were visited, and 61 EPDM roofs were inspected. This represented about 50 percent of the number of Air Force installations and buildings with EPDM roofing. The age of the roof systems ranged from 3 to 156 months, although 40 percent were only 30 months old or less. The inspections were performed by walking over the roofs during which notes were recorded and photos were taken. During the field visits, discussions were held with base engineering personnel to determine their views of the performance of EPDM roofing under their responsibility. Considering the relatively young age of the roofs inspected, their overall performance was found to be satisfactory. About half were visually seen to be in fine condition, while another third displayed only minor defects which were limited in scope and were considered to be readily reparable with routine maintenance. On a less positive note, in the latter case, the observed defects had gone without repair. This illustrated a key concern expressed by field personnel that they lacked ability to perform routine maintenance.

**12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)**

EPDM; field study; inspection; low-sloped roofing; membranes; performance; roofs; seams

**13. AVAILABILITY**

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- [X] ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

**14. NUMBER OF PRINTED PAGES**

77

**15. PRICE**

A04

ELECTRONIC FORM